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ABSTRACT

This instructional and resource guide is designed so that it may be used in the secondary school or in the first two years of college to present a series of units in space science, or to supplement existing science and mathematics courses. The guide consists of six units: (1) measurement, distance, and size in astronomy, (2) atoms, spectra, and stars, (3) atomic nuclei and stars, (4) the solar system, (5) the origin and evaluation of life, and (6) motion, rockets and gravity. Each unit is divided into the following parts: (a) a list of understandings that a student should have after completing study of the unit, (b) a topical outline of the material in the unit, with expositions, tables, demonstrations, and activities inserted when appropriate, (c) a list of sample questions, (d) problems and projects for further exploration, (e) audiovisual aids, (f) an annotated teacher bibliography and (g) an annotated student bibliography. Each of the units is basically self-contained. However, in general they require additional knowledge which may be obtained by a study of the earlier units, from the context of another course, or by a study of the material listed in the bibliographies. The material in the guide covers a range of difficulty levels, from grade nine through the first two years of college. (LC)

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SPACE RESOURCES FOR TEACHERS

SPACE SCIENCE

a guide outlining understandings, fundamental concepts, and activities

national aeronautics and space administration

SE 008 196

ED0 40047

SPACE RESOURCES FOR TEACHERS

SPACE SCIENCE

a guide outlining understandings, fundamental concepts, and activities

Developed at Columbia University
under the auspices of the Office of the Director of the
Summer Session, in cooperation with the Goddard
Institute for Space Studies

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 1969

preface

This guide was prepared from three successive presentations of a course in introductory space science offered by the Columbia University Summer Session, under the direction of Professor William A. Owens, to talented public school students in New York City. The course was offered to selected 11th and 12th graders in the summer of 1965 and to 7th, 8th, and 9th graders in 1966 and 1967. The course was also taught to one honor class and to two average ninth-grade classes at Rye High School, Rye, N.Y., in the 1966–1967 school year. Some of the material also has been used in undergraduate classes of the Columbia University Summer Session.

Finally, the material was presented to a group of 20 New York State teachers, in a 6-week graduate course at Columbia University in the summer of 1967, under the sponsorship of the New York State Department of Education and Columbia University. The teachers were particularly helpful in developing bibliographic and demonstration material. With this new material and suggestions made by the class, Malcolm Thompson, the instructor, prepared this updated and improved draft.

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introduction

A. SPACE SCIENCE, A UNIFIED PRESENTATION OF THE NATURAL SCIENCES

Space science is concerned with basic problems in science that can be studied with the aid of experiments carried out in space in a manner that is neither possible nor feasible by means of ground-based techniques. The techniques and theoretical concepts of space science are drawn primarily from physics, astronomy, the Earth sciences, and biology, but the problems which make up its substance are interdisciplinary in character. The major problems of space science center around developing an understanding of the origin and evolution of the universe, the formation of stars and planets, the origin of the solar system, the structure of the Earth as a planet, the atmospheres of the Earth and other planets, and the conditions in the history of the Earth and its atmosphere that relate to the origin of life on the Earth and the probability of extraterrestrial life.

The accompanying guide cuts across the barriers that separate a number of disciplines included in the modern organization of science. Although each discipline is an independent stream of research to the scientist working in the field, all illuminate a number of central problems. These problems are the identification of the basic forces that govern natural events; the role played by these forces in controlling the large-scale structure of the universe and its evolution in time; the interplay of forces involved in the formation of stars and galaxies; the origin of planets, such as the Earth, around the stars; the evolution of planets and their atmospheres; and the origin of life.

The following chronology indicates the succession of developments by which boundaries of the known world have been pushed back by scientific efforts in the last three centuries. Successively, since the 15th century, man has been forced to accommodate himself to the notion that the Earth is one of several similar planets circling around the Sun; that the Sun is one of many similar stars in the sky; that the Sun is an average member of a family of 100 billion stars clustered in the Milky Way galaxy; and that, as was discovered about 40 years ago, this huge galaxy is only one of a large number of galaxies scattered uniformly through all the regions of space within range of telescopes.

The enlargement of man's horizons in space and time, and the description of the physical events and forces which are believed to have led to the formation of the Earth and to the development of life on it, are fundamental intellectual contributions that science has made to the Western World—contributions which will be of the greatest interest to the general student.

B. ORGANIZATION OF THE GUIDE

The guide consists of the following six units:

I. Measurement, Distance, and Size in Astronomy
II. Atoms, Spectra, and Stars
III. Atomic Nuclei and Stars
IV. The Solar System
V. The Origin and Evolution of Life
VI. Motion, Rockets, and Gravity

Each unit is divided into the following parts:

a. A list of the understandings that a student should have after completing study of the unit
b. A topical outline of the material in the unit, with expositions, tables, demonstrations, and activities inserted where appropriate
c. A list of sample questions
d. Problems and projects for further exploration
e. Audiovisual aids
f. An annotated teacher bibliography
g. An annotated student bibliography

C. SUGGESTIONS FOR THE USE OF THE GUIDE

The guide has been designed so that it may be used in the secondary school or in the first 2 years of college to present a series of units in space science, or to supplement standard science and mathematics courses.

TO PRESENT A SERIES OF UNITS IN SPACE SCIENCE

Each of the units is basically self-contained. However, in general they require additional knowledge which may be obtained by a study of the earlier units, from the context of another course, or by a study of the material listed in the bibliographies. When a teacher uses the units as the basis for a unified presentation of space science, the subject unfolds in a logical sequence through the six units. The material in the guide covers a range of difficulty levels. Much of the guide has been used successfully with ninth-grade students. On the other hand, most of the units, when treated in depth, will be challenging to students in the 11th and 12th grades, and would be suitable for including in beginning science courses in the first 2 years of college.

TO SUPPLEMENT EXISTING COURSES

The guide, Table of Contents, and supporting materials have been arranged to make it convenient for the teacher to select topics for the enrichment of existing science and mathematics courses with materials from space science. The following discussion shows how material from the guide can be used to supplement standard topics in courses in physics, mathematics, chemistry, and biology. In fact, this use of the guide may represent its greatest value to many teachers.

A logical way to show how material in the guide can be used to enrich an existing course would be to make a detailed outline of the course and then list the topics in the guide which fit into each part. However, from a practical viewpoint, there is no way in which a detailed outline can be made which will fit all, or even a minute fraction of, existing courses.

Although certain topics are common to high school courses in science at a given grade level, there is much variation in details in courses presented in different schools, or even in the same school. Textbooks vary in the selection, organization, and development of content. Some textbooks have a "modern" orientation; others are traditional in nature. A course syllabus may be based upon several texts. Teachers vary in their training and interests. Students also vary in interest and competence.

In the light of the many variables mentioned above, it seemed best to arrange the Table of Contents so that it displays in detail the topics in the guide. The teacher can then, almost at a glance, identify topics which may be investigated for use as enrichment of standard topics in standard courses.

The following outline presents several suggestions for supplementary uses. It is not intended to be exhaustive. It indicates to the teacher a number of possibilities for enrichment use.

a. Physics

Textbooks vary in the emphasis given to measurement, though an understanding of the nature and use of measured data and of various units of measure is basic to practical work. Few textbooks even mention the methods and units used in measuring astronomical distances. Unit I supplies this information.

Although spectroscopy is a standard unit, few elementary physics textbooks apply it to a study of the stars. The use of the diffraction grating in spectroscopes is rarely mentioned. Information on these topics is found in Unit II.

Unit III will help the teacher apply a study of nuclear reactions to an understanding of the physics of the interior of stars.

Radioactive decay is likely to be studied in physics. Its use in dating the Earth is explained in Unit IV.

Many physics textbooks barely touch upon the subjects of planetary and satellite motion, behavior of rockets, and the gravity forces of bodies other than the Earth. Unit VI gives an introduction to these very interesting topics.

b. Mathematics

Basic to most work involving applications of mathematics is an understanding of the nature of measurement, units of measurement, scientific notation, and how to compute with approximate data. Many textbooks give inadequate treatment of these topics. Explaining Eratosthenes' method for measuring the Earth is a good exercise in geometry. Showing the relationship of the parsec to the radian is a challenge for the advanced student. These topics are introduced in Unit I.

Applications of the inverse square law will be found in various places in the guide.

The study of half life in Unit IV provides an opportunity for drawing and analyzing a graph.

The material in Unit VI is especially challenging in mathematics. Students can compute orbital velocities and periods, escape velocities, the final velocity of a rocket or launch vehicle, and the like. The teacher will find the books listed in the Teacher Bibliography to be of great assistance in developing this material.

c. Chemistry

The discussion in Unit I of the use of magnitudes to measure astronomical distances and the fact that certain stars always have the same absolute magnitude will be of interest to chemistry students.

The discussion of atomic structure can be greatly expanded by the use of materials in Unit II. The construction and calibration of a diffraction-grating spectroscope will add interesting material to the usual work on spectroscopy. The spectroscope can then be used to analyze some stellar spectra.

Unit III gives additional information on atomic reactions in the stars, how elements are made in stars, and application of the gas laws in stellar evolution. Cosmic abundance of elements is introduced. An example of a thought provoking question is: Why do compounds appear in stars in spectral classes K and M?

In Unit IV radioactive decay is related to finding the age of the Earth. The chemistry of planetary atmospheres is introduced.

Unit V presents the chemical conditions for the origin and evolution of life.

Unit VI presents such questions as why the energy released varies with different combinations of oxidizer and fuel.

d. Biology

Units III and IV introduce theories of the origin of the universe and trace the development of matter from the synthesis of elements in stars to the formation of the Earth, accounting for the abundance of elements necessary for the origin of life. Unit IV presents the environmental conditions needed for the maintenance of life on a planet.

Unit V cuts broadly across biology courses and may be used effectively to introduce the question of extraterrestrial life.

The teacher who carefully reads the following detailed Table of Contents will find many additional topics which can be used to reinforce or enrich his present science courses.

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Unit I

Unit I

MEASUREMENT, DISTANCE, AND SIZE IN ASTRONOMY

UNDERSTANDINGS TO BE DEVELOPED

At the conclusion of this unit the student should have the following understandings:

1. The measurement of small and large objects or quantities
2. A limited knowledge of statistical handling of data
3. The metric system
4. Triangulation
5. Parallax measurement
6. Scientific notation
7. The scale of the solar system
8. Stellar magnitudes and the inverse square law

Experience has shown that these understandings are basic to success with this guide. Pupils in the lower secondary grades will likely need review of the elementary mathematics of measurement. Some topics will be new to nearly all high school students and to many college students. The teacher should omit any topic in which he knows his students to be proficient.

A. NATURE OF MEASUREMENT

APPROXIMATE DATA

Practically all data in science come from measurement. Since no measurement is exact, all numbers obtained from measurements are approximations. Exact numbers are obtained only in the relatively few instances in which items can be counted. Precision in measurement requires the careful use of appropriate instruments and units of measure. The measuring system must be equally well adapted to items which are extremely small or extremely large.

Demonstration I–1

INSTRUMENTS FOR MEASUREMENT

Materials: meter sticks; 12-inch rulers; micrometer caliper; steel measuring tape; speedometer from a car or bicycle; transit; and perhaps devices for measuring volume, weight, wavelength, electrical current, light intensity, and radioactivity. Every device shown is briefly explained and demonstrated.

SIGNIFICANT FIGURES

All figures that indicate the precision or accuracy of a measurement are said to be significant. Thus, if 239,000 and 140,000 are each correct to the nearest thousand, each number contains three significant figures. Zeros are significant if they indicate the degree of precision or accuracy, but not if they merely locate the decimal point. When approximate numbers are added or subtracted, the result must be rounded off so that it has the same precision as the least precise of the numbers. When approximate numbers are multiplied or divided, the result must be rounded to the least number of significant figures in any number in the computation. Special rules apply for powers, roots, and averages.

SCIENTIFIC NOTATION

Computation with very large numbers, as in the measurement of stellar distances, and very small numbers, as in the measurement of atomic distances, is facilitated by the use of scientific notation. Numbers are expressed as powers of 10, with only one digit to the left of the decimal point. The total number of digits used indicates the precision of the measurement and therefore the number of significant figures. Each of the following numbers has three significant figures.

$$\begin{aligned} 586 &= 5.86 \times 10^{2} \\ 58600 &= 5.86 \times 10^{4} \\ .586 &= 5.86 \times 10^{-1} \\ .000586 &= 5.86 \times 10^{-4} \\ 93{,}000{,}000 &= 9.30 \times 10^{7} \end{aligned}$$

B. STATISTICAL ANALYSIS OF MEASUREMENT

A set of measurements can best be described and discussed if we know some of the statistical means of evaluation.

AVERAGE

If n measurements have been made, the arithmetical average or mean is obtained by dividing the sum of all n measurements by n.

DEVIATION

The difference between a measurement and some value n, such as the average calculated from the data, is called deviation.

RANGE

The difference between the largest and the smallest values in a collection of measurements is the range.

Activity I–1

STATISTICAL EVALUATION

(May be used as an assignment or a quiz.)

The values obtained from 1895 through 1965 by astronomers for the distance from the Earth to the Sun, called the astronomical unit (AU), are given below. Students are asked to compute the average, the range, and the deviation of each value from the average.

Date	*AU, millions of miles*
1895	93.28
1901	92.83
1921	92.91
1928	92.87
1931	93.00
1933	92.91
1941	92.84
1950	92.977
1950	92.915
1958	92.874
1959	92.876
1960	92.9251
1961	92.960
1961	92.956
1965	92.957

Why are there more significant figures in the measurements from 1950 on? The value of 92,957,000 miles (149,600,000 kilometers) was adopted by the International Astronomical Union in 1965.

C. MEASURING ORDINARY DISTANCES

Students will better understand the nature of measurement, the use of instruments for measurement, the problems of obtaining precise measurements, and the like if they measure some common objects.

Activity I–2

MEASURING A SMALL DISTANCE

The students are given the opportunity to estimate the thickness of a sheet of paper and then devise a method for measuring it. A good method is to take a pack of about 200 sheets, measure the thickness of the pack, and then divide by the number of sheets. The teacher should check the sheet thickness beforehand, if possible, with a micrometer caliper. A statistical analysis of results may be made to show significant figures, mean values, deviations, and the like.

Activity I–3

MEASURING A LARGER DISTANCE

This activity may take place in the school parking lot. The students use meter sticks to measure the lengths of various models of automobiles for various years. Groups of students should be assigned to different makes or models. The measurements may be checked against data obtained from local car dealers, and statistical analyses made as in *Activity I–2*.

Activity I–4

CONVERSION IN ENGLISH SYSTEM

(May be used as an assignment.)

The students are directed to convert the average values from *Activities I–1*, *I–2*, and *I–3* into inches, feet, yards, and miles.

12 inches = 1 foot
3 feet = 1 yard
1760 yards = 5280 feet = 1 mile

The students may need help in deciding whether to multiply or divide to get the proper unit.

D. THE METRIC SYSTEM

The units used in all measuring systems are divided and subdivided into smaller units to make measurements more precise and computation easier. For example, if the unit of measure in *Activity I–2* had been the mile, we would have had a very small fraction expressed with many zeros after the decimal point. On the other hand, if the AU were expressed in inches, we would have many digits to the left of the decimal point. Such numbers are difficult to work with.

In the course of any investigation, measurement must of necessity be transformed from one unit into another. The system of measure in which this may be accomplished most easily is the metric, which is based on the decimal system.

The basic unit in the metric system is the meter. One-fourth of the Earth's circumference equals about 10 million meters; 1 kilometer equals 1000 meters; 1 mile equals 1.609 kilometers. The metric system should be used, whenever possible, when presenting the material in this guide, with frequent conversions to English units.

Demonstration I–2

INTRODUCTION TO THE METRIC SYSTEM

Materials: meter sticks, transparent metric rule, opaque projector

Meter sticks are distributed to the students for examination. The divisions are detailed very carefully with a transparent metric rule on an overhead projector. The metric system may be compared with our monetary system. The prefixes should be very carefully noted.

$$\text{milli} = \frac{1}{1000}, \ \text{centi} = \frac{1}{100}, \ \text{kilo} = 1000$$

The students must be required to memorize these by drill and/or by a quiz.

Activity I–5

CONVERSION FROM ENGLISH TO METRIC SYSTEM

Activities I–1, *I–2*, and *I–3* are repeated using the metric system of measure.

Activity I–6

RELATION OF METRIC SYSTEM TO ENGLISH SYSTEM

With the completion of *Activity I–5*, the students continue to measure familiar objects: themselves, the desks, and so on. The objects are measured in both the English and the metric system and the equivalents are written on a chart. In all cases, the metric units are converted to meters, millimeters, centimeters, and kilometers. The class establishes conversion factors from English to metric units either by using proportions for any measurement or by taking the standard conversion factor from a book. The chart is then placed on the wall, and any English measurement that is encountered throughout the year is converted by the class and entered on the chart.

E. TRIANGULATION AND THE MEASUREMENT OF DISTANCES TO INACCESSIBLE POINTS

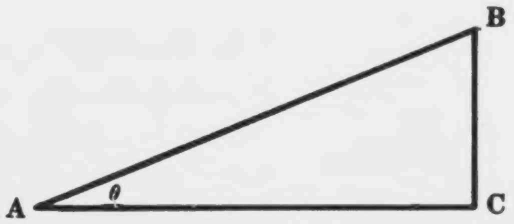
Triangulation is used by surveyors to measure distances which cannot be measured with a tape. Astronomers also use an extension of triangulation, the parallax, to measure distances to stars.

The theory of triangulation is based on the geometry of the triangle. If one side, the baseline, and the two base angles of a triangle are known, then the remaining sides can be found by one of three methods: drawing the triangle to scale and measuring the unknown parts, comparing similar triangles, and using trigonometric functions.

THE TANGENT FUNCTION

Our use of trigonometry will be restricted to the right triangle and the tangent function. The tangent of an acute angle of a right triangle is equal to the ratio of the side opposite the angle to the side adjacent to the angle. In the accompanying triangle,

$$\tan \theta = \frac{BC}{AC}$$



Thus, if we know three parts of the triangle, we can always find the remaining three parts. The value of the tangent for any angle and the angle that corresponds to a value for the tangent can be found in a table of tangent functions.

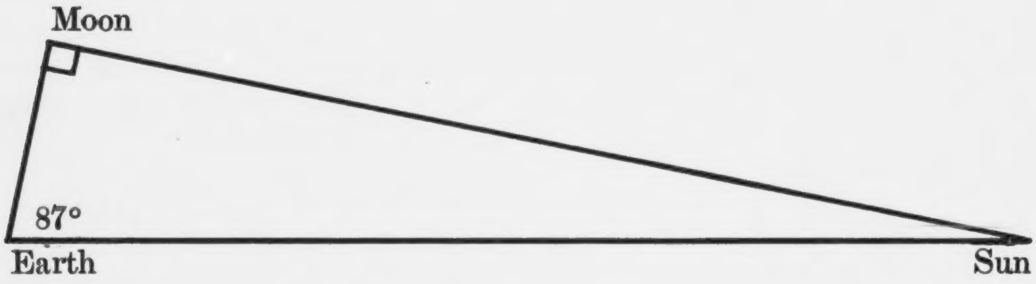
MEASURING THE CIRCUMFERENCE OF THE EARTH

Eratosthenes, about 200 B.C., knew that the Sun was directly overhead on the first day of summer in Syene, because he had seen its reflection in the bottom of a well located there. On the same day, he measured the angle of the Sun's rays in Alexandria, and found that they made an angle of 7.2° with the vertical. He inferred from the principles of geometry that the circumference of the Earth was 50 times the distance, about 500 miles, between Syene and Alexandria, thus concluding that the circumference was 25,000 miles. Today's measurement indicates that the diameter of the Earth is 7926.68 miles at the equator and 7899.98 miles at the poles. The circumference ranges from 24,860 to 24,900 miles.

MEASURING THE DISTANCE FROM EARTH TO SUN

The distance from the Earth to the Sun was measured historically by Aristarchus (third century B.C.) by triangulation. He used the distance from the Earth to the Moon as the baseline. He had no observer on the Moon, but he noted that at precisely half moon the angle subtended at the Moon from Earth to Sun was a right angle. He measured the angle between the Sun and Moon at Earth to be 87°, and concluded that the distance to the Sun is 20 times the distance to the Moon. This result is incorrect by a factor of 18. The actual distance to the Sun is 93 million miles, or 150 million kilometers. He should have measured $89\frac{5}{6}^\circ$.

Note the accompanying drawing. Did Aristarchus use the tangent function?



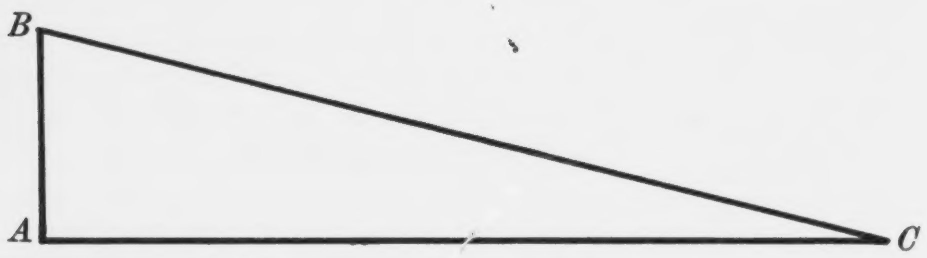
LUNAR DISTANCE

The distance to the Moon is determined by triangulation, using distant points on Earth for the baseline. The distance to the Moon is 238,900 miles; the diameter of the Moon is 2160 miles, which is approximately one-fourth the diameter of the Earth; the Moon's surface area is approximately one-sixteenth the surface area of the Earth.

Activity I–7

USE OF TRIANGULATION

Materials: rulers, protractors, table of trigonometric functions



C is a point in the classroom at some distance from the baseline *AB*, which can be measured. Line *AC* must be perpendicular to *AB*, unless we wish to use the more complicated trigonometric equations needed for oblique triangles. (A useful alternative is to use the school football field as a grid on which the students determine the distance to an object placed at an unknown yard line.)

After they have been oriented to the technique of triangulation and the method of calculation (the overhead projector is useful), the students actually take sightings with protractor and ruler and calculate the distance *AC*. The base of the protractor is held parallel to the baseline with the rounded portion toward the distant object. If a ruler is pivoted on the origin while the object is sighted along its edge, the desired angle may be read directly from the protractor. Additional problems, such as the width of the football field or the length of the basketball court, may be used for further practice.

Activity I–8

MEASURING THE HEIGHT OF THE SCHOOL FLAGPOLE

The students are allowed to develop their own techniques based on their experience with *Activity I–7*. The horizontal distance from the observer to the flagpole is the baseline, and the pole is assumed to be perpendicular to the ground. One procedure is to sight along the base of the protractor, with the rounded edge down. A string with a weight attached is fixed to the origin of the protractor. The string then indicates the vertical. If the angle at which the string crosses the scale is read, the angle of elevation from the sighting point can readily be computed. The students may suggest alternate means for determining the height of the pole.

a. If a stick of known length is placed in the ground on a sunny day, the length of its shadow and the length of the flagpole may be measured and the flagpole height determined by comparison of similar triangles. This method may be used to show the Sun angle in a discussion of Eratosthenes.

b. Measuring the rope on the pole is a quick and easy method of obtaining the height. The teacher may do this ahead of time to get an accurate height for the pole.

Demonstration I–3

THE TRANSIT

Materials: transit, steel tape, ruler, protractor

If a transit is not available in the school, it may be possible to borrow one from a local contractor or engineering firm. Occasionally, the father of a student may have access to one. If a surveyor or engineer brings the transit, he will probably be delighted to teach the fundamentals of the instrument.

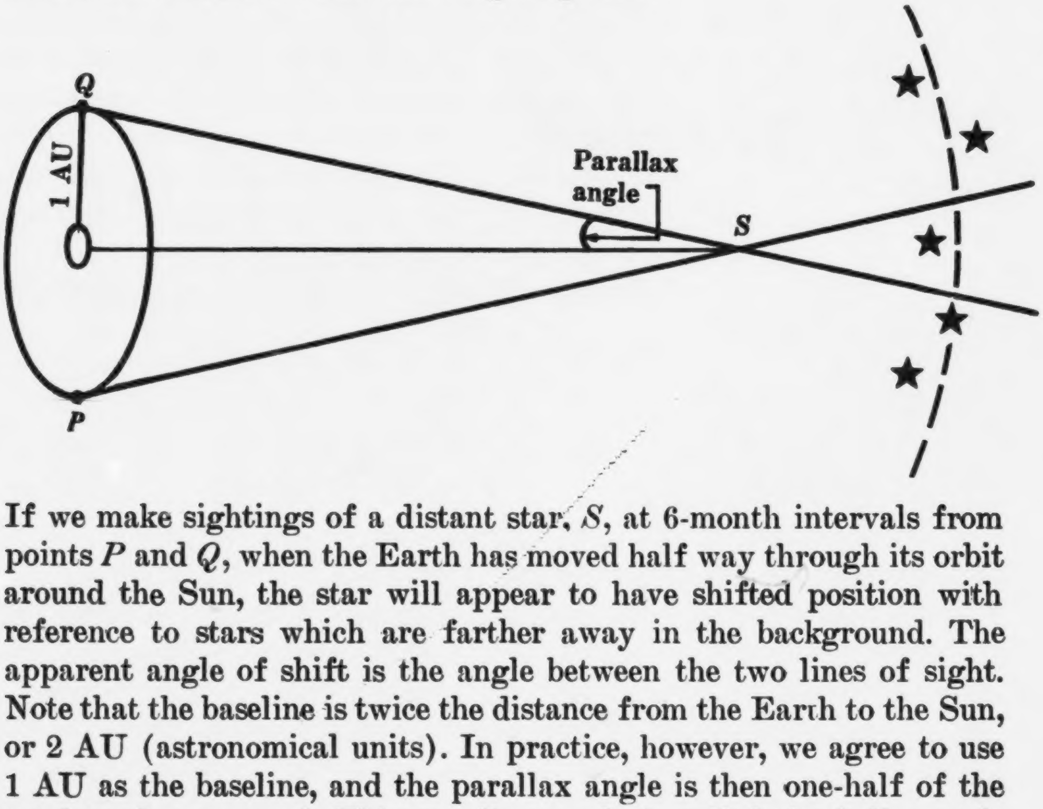
The transit is shown to the class and a comparison is made to the ruler and protractor, both in construction and operation. Each student should be given a chance to look through the telescope at some distant object.

The transit may be used for *Activities I–7* and *I–8* in conjunction with the ruler and protractor exercise or at the end of each activity for a check on the students' accuracy.

F. TRIGONOMETRIC PARALLAX AND THE MEASUREMENT OF ASTRONOMICAL DISTANCES

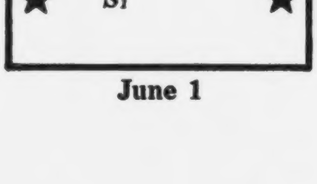
MEASURING THE PARALLAX ANGLE

Parallax is the apparent displacement of an object resulting from a change in position of the observer. If we hold up one finger at arm's length and look at an object with one eye closed, it appears to have a certain position with reference to objects in the background. If we close the first eye and look with the other, the finger appears to have shifted position with reference to the objects in the background. The use of parallax in making measurements of astronomical distances is illustrated in the following diagram.

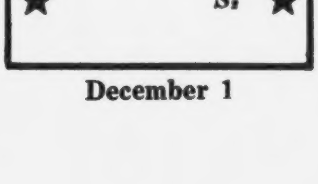


If we make sightings of a distant star, S, at 6-month intervals from points P and Q, when the Earth has moved half way through its orbit around the Sun, the star will appear to have shifted position with reference to stars which are farther away in the background. The apparent angle of shift is the angle between the two lines of sight. Note that the baseline is twice the distance from the Earth to the Sun, or 2 AU (astronomical units). In practice, however, we agree to use 1 AU as the baseline, and the parallax angle is then one-half of the total angle measured. This parallax angle is called the heliocentric parallax.

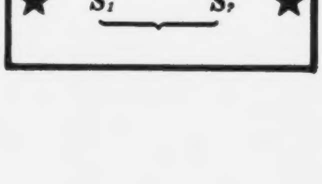
If the sightings were made on June 1 and December 1, photographs of S against its star background might look like the first two drawings below. Combining these into one photographic plate gives the third drawing, in which the amount of shift of S is indicated. Let us suppose



June 1



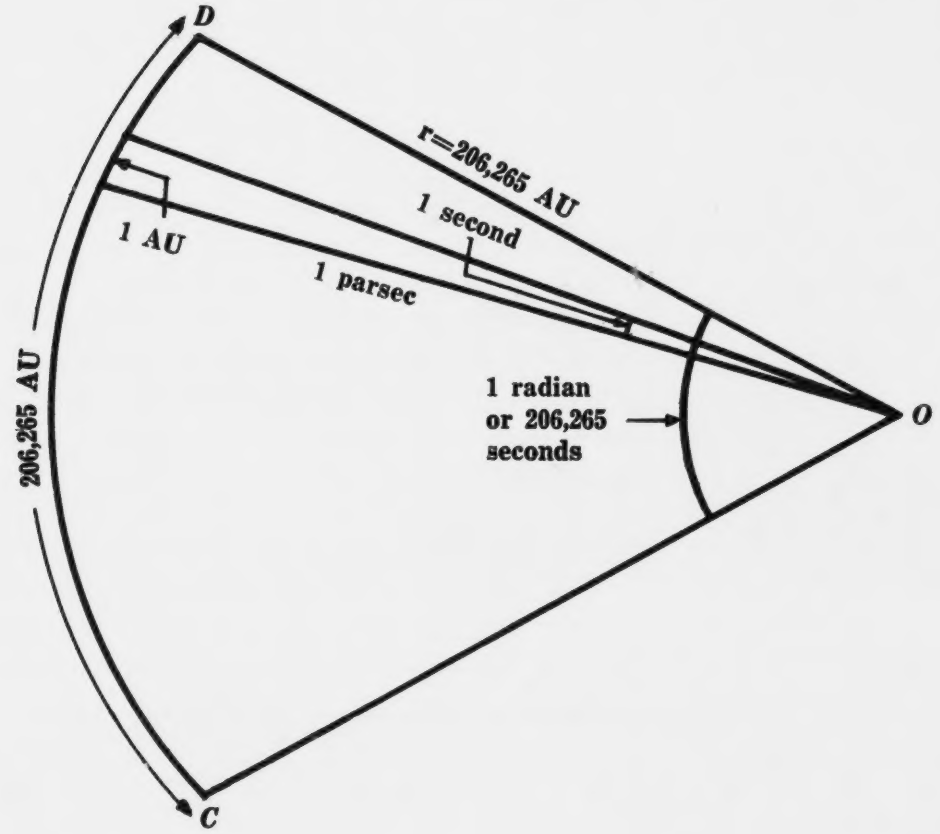
December 1



that enough sightings have been made of the two outside stars to give us accurately the angle between lines of sight from the Earth to them. If we assume that linear distance on the plate is proportional to angular measurement from the Earth, we can establish a scale or calibration for the plate. Measuring accurately the distance between the two stars enables us to find how large an angle is represented by each unit of linear measure. Knowing the scale, we can compute the angle represented by the shift S_1S_2. (The above assumption that the length of one side of a triangle is proportional to the opposite angle is not true of triangles in general, but it is valid for the very thin triangles involved in parallax measurement.)

THE PARSEC

Having measured the heliocentric parallax, there remains the need of finding a convenient and logical means of translating this measurement into a distance. This is done by using the radian. A radian is a central angle of a circle subtended by an arc equal in length to the radius. Since the circumference equals 2π times the radius, there will be 2π radians in the angle measure of a circle, so that 1 radian equals $360/2\pi$, or approximately 57.296°, which equals 3438 minutes, or 206,265 seconds. The sector of a circle shown in the following drawing has a central angle, O, of 1 radian, so that the arc CD of the sector contains 206,265 seconds of arc. Let us assume that the radius is extremely large, with 1 second of arc equal in length to 1 AU. Since the arc CD equals in length 206,265 AU, the radius also equals 206,265 AU. Then a central



angle of 1 second subtends an arc, or a baseline, of 1 AU. If a star were located at the center O, this angle of 1 second would be the parallax angle. A natural abbreviation for parallax of 1 second is parsec. Thus, if the baseline is 1 AU, as in the heliocentric parallax, a parallax angle of 1 second represents a distance of 1 parsec, equal to 206,265 AU.

UNITS FOR MEASURING ASTRONOMICAL DISTANCES

As the discussion above implies, the parsec is the fundamental unit for measuring great astronomical distances. The relationships among the various units are indicated below.

1 AU=92,957,000 miles=1.496×10^{8} kilometers
1 light-year (the distance light travels in 1 year at 186,300 miles per second)=5.88×10^{12} miles=9.460×10^{12} kilometers=63,280 AU
1 parsec=3.084×10^{13} kilometers=206,265 AU=3.26 light-years

(The measurements above are written with varying numbers of significant figures. Since our purpose is to explain ideas rather than to give engineering data, each of the above numbers might well be rounded to three significant figures for use with this guide.)

If the parallax angle is halved, it is evident that the number of parsecs is doubled. In general, if p'' is the parallax angle in seconds, the following relationship holds:

$$\text{Distance in parsecs}=\frac{1}{p''}$$

The greatest distance for which accurate parallax measurements can be made is about 100 parsecs. The parallax angle for this distance is 0.01 second. The closest stellar object is Alpha Centauri, which is 4.3 light-years away. There are about 1000 objects for which good parallax measurements can be made.

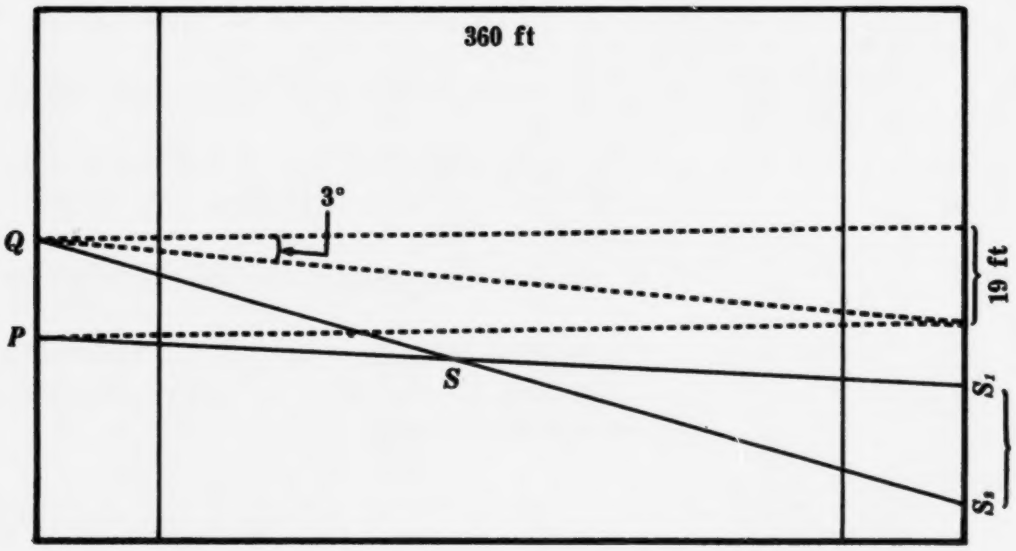
Demonstration I–4

THE METHOD OF TRIGONOMETRIC STELLAR PARALLAX

Materials: Polaroid camera, film, flash bulbs, objects, opaque projector

A student is placed on an unknown yard line of the football field, and pictures are taken from each side of the goalpost. In the second picture the student will appear to have shifted position relative to the goalposts at the far end of the field. The two photographs are projected onto a screen with an opaque projector, and the apparent shift of the student is measured. A drawing like the one below may be made showing the relative positions.

The goalposts are 19 feet apart, and the total length of the field is 360 feet. Using the tangent function to find angle Q, we note that tan $Q=19/360=0.0528$. Therefore angle Q equals about 3°. This gives us a scale or calibration of the photograph. The measured distance between the distant goalposts on the photograph, or on the



projection of the photograph on the screen, represents 3°. Using this scale, we can find the number of degrees represented by the linear shift of the student. (Remember that the actual distance to the student varies inversely with the size of the angle.)

The value of the exercise is that the teacher may present different clues to the solution. The number and kind of clues needed depend on the level of the class. It should be made clear that, because of the short distances and large angles involved, this demonstration is only an illustration of the method of stellar parallax and not an accurate method of measuring distances on the football field.

G. SCALE OF THE SOLAR SYSTEM

PLANETARY DISTANCES

If we use a scale such that the diameter of the Earth equals 1 inch, the Moon would be at a distance of 2.5 feet, the Sun would be at a distance of 300 yards, the distance from the Sun to Pluto would be 8 miles, and the distance to the nearest star would be 6 million miles.

Planet	Average distance from Sun		Sidereal period tropical years
	Million km	AU	
Mercury	57.89	0.387	0.24085
Venus	108.16	0.723	0.61521
Earth	149.60	1.000	1.00004
Mars	227.99	1.524	1.88089
Jupiter	778.4	5.203	11.86223
Saturn	1427	9.540	29.45772
Uranus	2869	19.18	84.013
Neptune	4498	30.07	164.79
Pluto	5900	39.44	248.4

Activity I-9

VISUALIZATION OF SCALE MODEL OF SOLAR SYSTEM

With the table of planetary distances, the students may attempt to construct a scale of the solar system which will fit on the football field. The scale may then be tried out on the field by letting the students be planets. The size of the students, however, cannot represent a scale of planet size.

Have one AU be equivalent to 3 yards. The students may make large signs for each planet and a picture from the bleachers may be taken to give the overall effect. A scale of solar and planetary size may be calculated in the classroom and then constructed with paper circles.

H. STELLAR MAGNITUDES AND THE MEASUREMENT OF ASTRONOMICAL DISTANCES

MAGNITUDE SCALE

The relative brightnesses of stellar objects is expressed by a magnitude scale. A difference in brightness of one magnitude means a brightness ratio of 2.512. A star of first magnitude is 2.512 times as bright as a star of second magnitude, which is 2.512 times as bright as a star of third magnitude, and so on. Using a more concise mathematical notation, a star of first magnitude is $(2.512)^2$ times as bright as a star of third magnitude.

Continuing this process, we note that a star of first magnitude is $(2.512)^5=100$ times as bright as a star of sixth magnitude. A difference of five magnitudes means a brightness ratio of 100. Note that the greater the brightness of the star, the lower is its magnitude number. Thus, the magnitude of an extremely bright star will be represented by a negative number.

APPARENT MAGNITUDE

The apparent magnitude of a star is its brightness as it appears to an observer on Earth. Apparent magnitudes are measured by visual, photographic, or other means.

ABSOLUTE MAGNITUDE

Absolute magnitude is the apparent magnitude that a star would have if viewed from a standard distance of 10 parsecs.

There is a mathematical relationship connecting absolute magnitude, apparent magnitude, and distance:

$$M = m + 5 - \log d$$

In this equation, M = absolute magnitude, m = apparent magnitude, and d = distance in parsecs. If we know the absolute magnitude of a star and can measure its apparent magnitude, we can compute its distance in parsecs. From this value we can readily check the parallax angle of nearby stars.

A certain type of blue star seems always to have the same absolute magnitude. This conclusion is based upon the observation of stars of this type within the range of trigonometric parallax. The absolute magnitude is then used in the above formula to determine the distance to the blue stars beyond the range of trigonometric parallax. If the blue star is in a cluster or in a nearby galaxy, then the distance to the cluster or galaxy is assumed to be the same.

Star	Constellation	Apparent magnitude	Absolute magnitude	Distance (light-years)
Sun		−26.8	4.9	
Rigel	Orion	0.34	−6.4	600
Procyon	Canis Minor	0.53	2.7	11
Altair	Aquila	0.89	2.3	16
Betelgeuse	Orion	0.92	−5.8	600
Aldebaran	Taurus	1.06	−0.7	57
Alpha Centauri	Centaurus	−0.27	4.5	4.3
Sirius	Canis Major	−1.52	1.5	9
Vega	Lyra	0.14	0.5	27
Capella	Auriga	0.21	−0.6	48
Arcturus	Bootes	0.24	−0.3	38

CEPHEID VARIABLES

These are pulsating stars whose luminosity changes periodically. It has been found that the amount of change in luminosity, or absolute magnitude, is related to the length of the period. This means that any cepheid variable star, wherever it is located in the universe, will have the same absolute magnitude as every other cepheid variable with the same period. Thus, the measurement of the period enables us to use the equation in Section H to compute the distance to the star.

In nearby galaxies which can be resolved into individual stars and therefore whose distances may be determined by the variable stars, it has been found that there is a red Doppler shift which is proportionate to the distance. This rule has been applied to galaxies which cannot be resolved into individual stars to determine distance. To date, the object with the greatest shift, the quasar, may be 8 billion light-years away!

Demonstration I–5

APPARENT AND ABSOLUTE MAGNITUDE

Materials: four light bulbs of different wattages, a photoelectric cell or light meter, and a lamp

Apparent magnitude: One light is placed at some distance from the photoelectric cell and the reading is recorded. The photoelectric cell represents the earthbound observer, and the bulb represents a star. A second light of different wattage is placed at the same distance, and the reading is recorded. The second light is then moved until the reading is the same as with the first bulb. Clearly, two stars of different intrinsic brightness may appear to have the same brightness on Earth. The amount of motion toward or away from the photoelectric cell shows that distance influences apparent brightness.

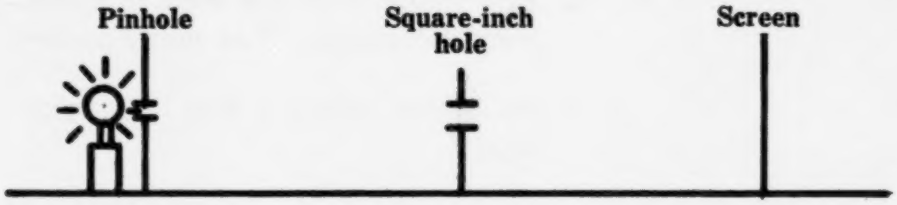
Absolute magnitude: The bulbs are arranged at a standard distance and readings are recorded for each one. This is repeated at a second distance to see whether the photoelectric cell reading can be correlated with distance. If it can, the students may try to determine unknown distances for known wattages or unknown wattages for known distances.

Demonstration I–6

THE INVERSE-SQUARE LAW

Materials: cardboard with an opening 1 inch square cut in center, translucent screen 4 inches square marked with square-inch grid, light source, meter stick, and cardboard with pinhole

Arrange materials as below. (Screen may be made with shirt board and tissue paper.)



The pinhole cardboard must be placed in front of the light to obtain a point source. The cardboard is placed 1 foot from the light. The screen is then moved away from the cardboard until four squares are illuminated. Distance to light is measured and recorded. This is repeated for 9 square inches illumination and 16 square inches illumination. All data are tabulated, and students attempt to derive the equation for the inverse-square law:

$$\text{Apparent brightness} = \frac{\text{absolute brightness}}{d^2}$$

SAMPLE QUESTIONS

1. Convert to scientific notation:
   - a. 0.000052
   - b. 5200000
   - c. 52
   - d. 0.5100000
   - e. 750000000000
   - f. 0.000000000031

2. Convert to decimals:
   - a. 7.3×10^{-7}
   - b. 7.3×10^{0}
   - c. 5.12×10^{9}

3. Complete the following mathematical operations:
   - a. $(2 \times 10^{5})(3 \times 10^{7}) =$
   - b. $(4 \times 10^{47})(5 \times 10^{13}) =$
   - c. $(7 \times 10^{-5})(6 \times 10^{4}) =$
   - d. $\frac{7 \times 10^{5}}{7 \times 10^{5}} =$
   - e. $\frac{14 \times 10^{16}}{7 \times 10^{4}} =$

4. Convert the following:
   - a. 15 cm=________m
   - b. 2173 m=________cm
   - c. 4865 m=________km
   - d. 152 mm=________m
   - e. 152 m=________km
   - f. 152 mm=________km
   - g. 75 cm=________mm
   - h. 982 m=________mm

5. A baseline is 100 meters long. The angle at one end of the baseline is 90° with a line drawn to a distant object. The angle formed by a line to the same object with the other end of the baseline is 10°. How far is the object from the first end of the baseline?

6. How many miles are there in a light-year? How many feet? How many kilometers? How many meters?

7. An object which is 652 light-years away is how many parsecs away?

8. If a star 1 parsec away shows a parallax of 1 second of arc, and if 1 parsec=3.26 light-years, what is the parallax of the nearest star Alpha Centauri, which is 4.3 light-years away?

9. If a star 400 light-years away has an apparent brightness of 16 units, what apparent brightness would the same star have if it were 800 light-years away?

10. What factor makes the metric system easy to use?

11. List the prefixes used in the metric system and show the numerical meaning of each.

12. What method of stellar distance determination is the basis for all other methods?

13. Describe a way to measure the circumference of the Earth without pacing it off.

14. Explain the difference between absolute and apparent magnitude.

15. What is the relationship between the amount of light received on Earth and the amount of light emitted by a distant object?

16. How is the distance to objects beyond the parallax determined? How are these methods dependent on the parallax method?

17. What is the importance of determining stellar distances?

PROBLEMS AND PROJECTS FOR FURTHER EXPLORATION

1. Using a transit and a rod, survey all or part of your school grounds in both the horizontal and the vertical plane. Make a scale map of what you have surveyed.

2. Conduct a research project to find other applications of the inverse-square law.

3. Develop a series of photographs to explain trigonometric parallax.

4. How do astronomers determine the distance to galaxies that cannot be resolved into individual stars?

5. Look at the stars on the next clear night to see if you can determine whether the apparent bright stars are very close or intrinsically bright, or both. Using a star chart and a distance table for bright stars, check your answers.

AUDIOVISUAL AIDS

MEASURING LARGE DISTANCES (20 min.) color Modern Learning Aids. Using models of the Earth, Moon, and stars, this film describes the place of triangulation, parallax, and the inverse square law for light in geophysics and astronomy. Demonstrations point up the immensity of interstellar space and suggest the complexities of measurement on this scale. This is an excellent film for the average and above-average high school student.

THE SHAPE OF THE EARTH (Geodesy) (27 min.) color McGraw-Hill Films. A rather advanced film dealing with the size and shape of the Earth. Determination of position and of distances on the Earth by astronomical means is examined. Problems such as the irregularity of rotation of the Earth and the unreliability of a simple plumbline measurement are examined.

TRIGONOMETRY MEASURES THE EARTH (28 min.) color Modern Learning Aids. Shows in some detail how Eratosthenes used trigonometry and shadows cast by the Sun to measure the circumference and diameter of the Earth. A method of finding the distance to the Moon by trigonometry is also described as an example of the power of trigonometric concepts.

SPACE NAVIGATION HQ 116 1967 (21 min.) color National Aeronautics and Space Administration. Illustrates with animation and live action the methods used to determine position in space and to correct trajectories of unmanned and manned spacecraft. It also shows the use of a computer aboard the Apollo command module.

MEASURING LARGE DISTANCES (29 min.) b/w Modern Learning Aids. PSSC physics film.

SHORT TIME INTERVALS (21 min.) b/w Modern Learning Aids. PSSC physics film.

THE METRIC SYSTEM (13 min.) color McGraw-Hill Films.

MEASUREMENT (21 min.) b/w Modern Learning Aids. PSSC physics film.

Addresses are listed in the Appendix.

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Addresses are listed in the Appendix.

Unit II

Unit II

· ATOMS, SPECTRA, AND STARS

UNDERSTANDINGS TO BE DEVELOPED

At the conclusion of this unit the student should have the following understandings:

1. The nature of elements, compounds, and mixtures
2. The nuclear atom and its relative size
3. The basic forces in nature
4. Energy and the electromagnetic spectrum
5. Atomic spectra and the spectroscope
6. The spectra of stars and the use and value of the Hertzsprung-Russel diagram

A. FORMS OF MATTER

ELEMENTS

Matter may be made of elements, either individually or in combination. An element is the simplest form of a substance that has the properties of that substance but contains only atoms of one type. Iron, gold, oxygen, hydrogen, and uranium are examples of elements. Should only one atom of a substance be available, even that atom is called an element. As of 1969, there are 104 known elements.

Demonstration II–1

PROPERTIES OF ELEMENTS

Elements in all three states are displayed for the students. (The gaseous state may be reserved until *Demonstration II–2* if this is more convenient.) It should be stressed that an element cannot be broken down further by ordinary chemical and physical means. Some of the elements chosen should show unique physical properties, such as carbon and mercury. Others should show similar physical properties, such as aluminum and zinc. Both the zinc and the aluminum may be tested with acid to see which reacts. The zinc will react with the acid to liberate hydrogen. Similar chemical reactions may be used to show that even though elements may appear the same physically, the only sure way of identifying an element is chemically.

COMPOUNDS

If two or more different atoms (elements) are joined together chemically, this combination of different atoms is called a compound. If iron and oxygen combine to form a compound, the result is rust. Hydrogen and oxygen combine to form water. Sodium and chlorine, both elements, combine to form ordinary table salt. One of the many compounds of carbon, hydrogen, and oxygen is sugar.

The smallest unit of a substance which has the properties of the substance is called a molecule. If the substance is an element, the molecule consists of one or more atoms of the same kind. If the substance is a compound, then the molecule consists of a combination of two or more different atoms. A molecule of water contains two atoms of hydrogen and one atom of oxygen. A molecule of oxygen, on the other hand, contains just two oxygen atoms. A molecule of sugar sucrose contains 12 atoms of carbon, 22 atoms of hydrogen, and 11 atoms of oxygen.

Demonstration II–2

COMPOUNDS

The electrolysis of water is performed in a standard cell to show that water may be broken down into two different materials. The two gases may be bled off into test tubes and a glowing splint may be thrust into each to prove that they have distinctly different properties. (The splint will burst into flame in the oxygen, while a mild explosion, which will not break the tube, will occur in the hydrogen.) The hydrogen produced is greater in volume than the oxygen by a factor of 2. This observation may be used to introduce the idea of combining volumes or may be noted for later use. The hydrogen is lighter than air and the oxygen is heavier than air; therefore the tubes should be held upside down and right side up, respectively.

This demonstration shows that water is not an element, but it does not necessarily show that hydrogen and oxygen are elements. Also, it may be pointed out that the properties of a compound are wholly different from those of its individual components. The demonstration may be supplemented with similar reactions, such as combining sugar and concentrated sulfuric acid, which liberates carbon.

MIXTURES

If one puts sugar in a paper cup and then pours in water, the resulting material, even after vigorous mixing, is still sugar and water. One can remove the water from the mixture by boiling it away. Another example of a mixture is air, which contains oxygen, nitrogen, carbon dioxide, water vapor, and dust particles.

Demonstration II–3

MIXTURES

The fact that mixtures retain the properties of the components may be demonstrated by mixing iron filings and sugar and passing a magnet through to removing the filings. It should be stressed that a mixture can be separated physically, but a compound can only be separated chemically.

B. THE NUCLEAR MODEL OF THE ATOM

In 1868 Dmitri Mendeleev realized that since all elements are different, it is possible to classify the elements in order according to certain distinguishing features. It was assumed that the distinguishing features or properties of the elements were a manifestation of the atoms of which they were composed. The nature of these atoms was obscure, but they seemed to involve negative and positive electrical charges.

Demonstration II–4

THE ELECTRICAL NATURE OF ATOMS

Standard static electricity demonstrations and/or activities may be used to show that the electrical charges come from the matter involved and that there are two kinds of electrical charges. The attraction and repulsion of unlike and like charges, respectively, should be noted in order to construct the nuclear model of the atom.

THE BOHR ATOM

Every atom contains a nucleus and at least one orbiting electron. In the early 1900's Rutherford and Bohr proposed an atomic model to explain these features. This solar system analogy of the orbiting electrons is not valid in light of present theories of the structure of the atom, but it is perhaps the easiest to visualize.

The nuclear model was proposed following an experiment in Rutherford's laboratory in which positively charged alpha particles were beamed at a thin sheet of gold foil. To Rutherford's surprise most of the alpha particles passed through the foil, but a few were reflected back. This behavior could only be explained by assuming that the atom was mostly empty space, but contained a massive positively charged nucleus. The fact that atoms in the free state appear to be neutral meant that there must be an equal number of negative charges in the atom, but not necessarily in the nucleus. Hence, the orbiting electron model.

Demonstration II–5

RUTHERFORD'S ALPHA-SCATTERING EXPERIMENT

A large cardboard box open at both ends is set up so that the students cannot see in the open ends. A brick is placed in the box. The teacher throws a rubber ball through the box a dozen times, or until the ball hits the brick and bounces back. The students attempt to describe the contents of the box, and compare the results of the demonstration with the conclusions drawn by Rutherford relative to the atom.

The last three Surveyor spacecraft (V, VI, and VII) had on board alpha-scattering experiments in which lunar surface material was used as a target instead of gold foil. By measuring the energies of alpha particles after bombardment of the surface material and of emitted protons as a result of bombardment, scientists have concluded that the surface of the Moon is primarily basaltic.

The simplest atom is hydrogen, which has one proton in the nucleus and one orbiting electron. Since all protons are positively charged, the number of protons contained in an atom's nucleus must be balanced by an equal number of negative charges, if the atom is going to be electrically neutral. These negative charges are electrons. For example, oxygen has eight protons in the nucleus. It, therefore, has eight electrons orbiting the nucleus. In addition to the protons in the nuclei of atoms, most kinds of atoms have neutral particles in the nucleus called neutrons.

The number of protons in an atom's nucleus is called the atomic number. The major feature which distinguishes atoms from one another is the atomic number. If we add the number of protons and the number of neutrons in a nucleus, the sum is called the mass number. If we add the weights of all the protons and the neutrons in a nucleus, the sum is called the atomic weight. Usually one can find the mass number of an element by rounding off the atomic weight to the nearest integer.

PERIODIC TABLE

Mendeleev arranged the known elements according to their atomic weights to form a periodic table. In the present periodic table the elements are arranged according to atomic numbers. Symbols are usually employed in such a table, ${}_8O^{16}$, for example. The subscript 8 indicates the number of protons in the nucleus. The number of neutrons is found by subtracting the number of protons from the number 16. The symbol O stands for oxygen. Hence, there are eight protons, eight neutrons, and eight orbiting electrons in the oxygen atom. All 104 elements are listed this way in the periodic table.

Activity II–1

THE PERIODIC TABLE

Following the presentation of the periodic table, the students are given the opportunity to assemble models of atoms. This may be done graphically with wire and three different colors of clay. If this appears to be too elementary for the class, an alternative method is to use the overhead projector with three different geometric shapes of cut paper to represent the three basic particles. With the periodic table in view the teacher assembles different atoms on the projector and the students identify each atom and record the mass number and the atomic number. This activity is particularly good if used as a quiz.

C. SIZE OF THE ATOM

The size of an atom is impossible to visualize. It is known, for example that the diameter of the hydrogen atom, measured at the orbit of the electron, is 1.58×10^{-8} centimeter. We can illustrate the small size of the atom as follows: if the hydrogen atom were 1 millimeter in diameter a man would be about 32,000 kilometers tall. In addition, it is known that the diameter of the hydrogen nucleus, that is, of the single proton, is 2.90×10^{-13} centimeter. If the nucleus were the size of the Sun, the orbiting electron would be at a distance four times farther than the orbit of Pluto.

Despite the fact that the proton and the electron have the same magnitude of charge (at least to the 20th decimal place), the mass of the proton is 1836 times greater than the mass of the electron.

Activity II-2

SCALE OF THE ATOM

Using 1.5×10^{-8} centimeter as the size of the entire atom and 2.9×10^{-13} centimeter as the size of the nucleus, the students may construct a scale for the atom using the football field as a convenient grid. If the nucleus were 2 millimeters in diameter and placed on one goal line, the nearest electron would be located at about the opposite goalpost. The scale of the solar system may be superimposed on the atomic scale for purposes of comparison.

D. THE FOUR FORCES

DESCRIPTION AND COMPARISON

Gravitational and electrical forces are readily apparent to even the casual observer. These forces may easily be demonstrated by dropping an object and by observing the motion of charged objects when they are brought near each other. In answer to the question of why the nucleus of a uranium atom does not fly apart because of the electrical repulsion of the protons, one might think that protons are so close that gravitational force holds them together. This would mean that the gravitational force is stronger than the electrical force. Careful experimentation has shown, however, that the electrical force is 10^{36} times greater than the gravitational force. This means that a third force, stronger than the electrical force, must hold atomic nuclei together. This force acts over a very short range of distance and is called the nuclear force. Research in nuclear physics has pointed to the existence of a fourth force in nature which governs the decay of certain particles. This force is called the weak force and will not be discussed. Below is a list of the four forces of nature and their relative strengths:

Force	*Relative strength*
Gravitational	10^{-38}
Electrical	10^{-2}
Weak	10^{-20}
Nuclear	$10^{0} (=1)$

Both neutrons and protons display the strong force. It is convenient, therefore, to think of the neutrons as counteracting the electrical force of repulsion within the atom by increasing the nuclear force.

Demonstration II–6

THE NUCLEAR FORCE

Fix a spring between two blocks of wood so that force must be used to compress the spring as the blocks are brought closer together. The spring represents the electrical force of repulsion. A hook is attached to one block and an eye to the other to represent the short range, strong nuclear force. When the blocks are close to each other the strong force holds them together. The electrical force continues to operate as does the spring in the model. This same model may be used to show energy release in nuclear fission.

E. ENERGY

Since matter can only interact with other matter via the basic forces in nature, the forces govern all the events which take place in the physical world. When the interaction takes place, energy is released or transferred from one object to the other. Energy is defined as the ability to do work. One object does work on another object when they interact, thus transferring energy. For example, object *A* collides with a stationary object *B*, setting *B* in motion and slowing down *A*. *A* has done work on *B*, and *B* is now more able to do work on some object *C*, while *A* is less able to do work. Therefore, by the definition given abve, energy is transferred from *A* to *B*. The greater the ability of an object to do work, the higher the energy state of the object. When an object goes from a high energy state to a lower energy state, it must give up energy in some form. If the objects are pool balls, then the force by which they interact is the electrical force as the electron clouds surrounding the atoms of one ball repel the electrons in the clouds surrounding the atoms of the other ball.

There are two distinct classes of energy: potential and kinetic.

POTENTIAL ENERGY

Potential energy is possessed by a compressed spring, a stretched rubber band, a stick of dynamite, a boulder ready to tumble down a hill, and the nucleus of a uranium atom.

KINETIC ENERGY

Kinetic energy is exhibited by all moving objects, whether they are flying mosquitos, moving air molecules, or swiftly moving asteroids.

CONSERVATION

Energy is a conservative quantity. The total amount of energy, potential or kinetic, prior to an event must equal the total amount of energy after the event. This law of conservation of energy applies to all events in the physical world except nuclear reactions in which matter is converted to energy or energy into matter. Since matter is a conservative quantity as well, the two laws must be combined to read, "Matter and energy cannot be created or destroyed but may be interchanged." The profound significance of this statement is that it leads to the conclusion that the total amount of matter and energy in the universe is constant. However, by considering individual systems of matter and energy one can say that energy is expended or absorbed by the system when the energy leaves or enters the system.

Demonstration II–7

ENERGY

Demonstrate the transfer of energy from one object to another by causing balls or marbles to collide on the demonstration desk. Show the transfer of kinetic to potential energy by rolling a ball up an inclined plane: as the ball slows down, the kinetic energy is converted to potential energy. The reverse is true when the ball rolls back down the plane. Lift a book from the floor to the table top. The book has gained potential energy. Where did it come from? Can it be seen? As the book falls to the floor, it loses potential but momentarily gains kinetic energy until it strikes the floor, where it releases all its energy in the form of heat, sound, and vibrations of the building.

F. ELECTROMAGNETIC RADIATION

QUANTA OF ENERGY

Energy may be transmitted across space whether matter is present in the space or not. When an electric current is set up in a conductor, a magnetic field is produced. The field travels outward from the conductor at the speed of light. If there is another conductor nearby, the magnetic field will "push" the electrons in the conductor; hence the field does work. If the current is shut off, the field collapses at the speed of light and the electrons in the second conductor "fall back." The direction of current flow in the first conductor determines the direction of the magnetic field and hence the direction in which the electrons are pushed in the second conductor. If the electric current oscillates in the first conductor, then waves of magnetism flow out from the conductor and cause the electrons in the second conductor to oscillate with the same frequency. The waves of magnetism are actually bundles or packets of energy called quanta or sometimes photons. This overall type of energy is called electromagnetic radiation for obvious reasons, and the above sentence describing the oscillating electron device is basically the description of a radio transmitter and receiver.

Radio waves are low frequency, long wavelength, electromagnetic waves. If the frequency is progressively increased, then the waves become shorter and increase in energy according to the relation

$$E=\frac{hc}{\lambda}$$

where E is the energy, h is Planck's constant, 6.62×10^{-34} jouleseconds, c is the speed of light, 3×10^{8} m/s, and λ is the wavelength. Since $c=\lambda F$, where F is the frequency, the first relation may be stated as $E=hF$.

When matter is heated it emits electromagnetic radiation. In fact, the black-body radiation law states that any object which is at a temperature above zero degree absolute (Kelvin) radiates energy. The power of the radiation is proportional to T^4, while the wavelength of peak intensity is proportional to T^{-1}. These relationships are shown by Stephan's law and Wien's displacement law, respectively. In the visible spectrum, different colors represent different wavelengths or energies. Red has the longest wavelength (lowest energy) and violet has the shortest wavelength (highest energy).

Activity II-2

ELECTROMAGNETIC WAVES

The students connect a direct current source to a coil of wire and, using a compass, verify that a magnetic field is produced by the current. With some preliminary instruction on currents and magnetic fields, the students may attempt to establish a rule for current flow and direction of field by reversing the current direction through the coil and observing the behavior of the compass.

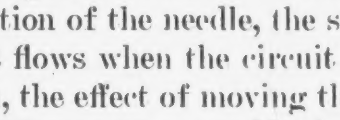
A second coil of wire connected to a galvanometer may be placed in the vicinity of the first and the circuit of the first made and broken. The galvanometer needle moves because of the induced current in the coil and not because the magnetic field acts directly on the needle. By carefully noting the action of the needle, the students may determine which way the current flows when the circuit is made, which way it flows when it is broken, the effect of moving the coil in the field, and, though difficult, they may even try to verify the inverse square law for radiation. By rapidly opening and closing the switch, the students may produce electromagnetic waves. If a radio is brought into class, the snaps of the opening and closing circuits may be amplified to illustrate their nature. This activity may be used as a demonstration if the required materials are not available in sufficient quantity.

Demonstration II-8

THE ELECTROMAGNETIC SPECTRUM AND THE RELATION $C=\lambda F$

A chart or a mimeographed handout of the electromagnetic spectrum is presented to the students, and the sequence of types of radiation is thoroughly covered. If it is pointed out that all electromagnetic radiation travels at the same velocity, then the relationship $C=\lambda F$ may be made clear in the following demonstration.

Obtain five or six pieces of wood of length L and twice the number of length $\frac{1}{2}L$. The wood is arranged as follows:



If both lines of blocks are pushed past a point P at the same speed, then clearly the number of small blocks passing the point is greater than the number of large blocks. If frequency is defined as the number of waves passing a point per unit time and if the length of the blocks is said to represent wavelengths, then it becomes clear that as the wavelength increases the frequency decreases. Conversely, as the wavelength decreases the frequency increases, if the velocity is constant. Mathematically, $C=\lambda F$.

Demonstration II–9

ENERGY AND THE COLOR OF LIGHT

Materials: unfrosted incandescent lamp, wire, tongs, socket, Bunsen burner, and variable voltage source

Connect the lamp to the variable voltage source and gradually increase the flow of electricity. When the temperature of the filament of the bulb is slowly raised as we pass more and more electrical current through it, it produces very high frequency radio waves, then infrared waves, then visible light waves. If the temperature could be raised still farther without destroying the filament through vaporization, X-rays would eventually be produced. The radiation is produced by the effect of the heat on the electrons of the atoms making up the filament. This progressive increase in the energy of waves emitted as heat is applied may be demonstrated by pointing out the color of the light as more and more current is passed through the filament. The visible color starts at red, then goes to orange, yellow, and finally to white, which is a mixture of all colors (including blue and violet). A similar demonstration may be performed by heating a wire in a Bunsen flame.

G. VISIBLE LIGHT SPECTRA

TEMPERATURE OF STARS

All the energy that impinges on the Earth from space that does not come in the form of discrete particles of matter is some type of electromagnetic radiation; visible light, infrared, ultraviolet, X-ray and gamma radiation, and radio waves. The Sun and stars are emitting most of this radiation. If the visible light from these celestial objects is passed through a prism or diffraction grating, it breaks up and produces a spectrum of its component colors or wavelengths. Astronomers measure the amount of radiation at each wavelength to determine the wavelength of maximum radiation. Once this is determined, then the temperature of the Sun or stars may be determined using Wien's law $T\ ^{\circ}K=(0.289/\lambda\ \text{max})$ where 0.289 is the constant of proportionality. Thus, by causing the energy emitted from objects at great distances to interact with matter on the Earth, the temperatures of the distant objects may be determined.

Activity II–3

CONTINUOUS SPECTRA AND THE MEASUREMENT OF COLOR INTENSITY

Materials: photoelectric cells, galvanometers, wire, prisms, incandescent lamps

The students are directed to produce a continuous spectrum on a white piece of paper by passing sunlight or light from an incandescent lamp through a prism. Then, with the photoelectric cell, they measure the intensity of light at each wavelength by reading the galvanometer. This activity may be used as a demonstration and, if a variable voltage source is used in conjunction with the incandescent lamp, a direct correlation may be made between heat and color.

Activity II–4

OBSERVATIONS OF STARS OF DIFFERENT TEMPERATURE

Direct the students to look at certain specific stars to determine the colors of each. In the fall two good stars are Vega and Arcturus. In the winter Rigel and Betelgeuse are readily visible. The students should predict the relative temperatures of each star observed compared to each other and to the Sun.

Star	*Color*
Vega	White
Rigel	Blue White
Arcturus	Orange
Betelgeuse	Red
Sun	Yellow

H. ATOMIC SPECTRA

ENERGY LEVELS

The light that comes from an operating electric light comes from the motion of electrons in the luminous material.

Consider the simplest of all atoms, hydrogen, which has only one orbiting electron. Quantum mechanics states that the electron may not occupy just any region around the nucleus, but must exist in one of a fixed number of orbits or energy levels. The different energy levels describe the different amounts of energy the electron may have as it moves about the nucleus. As with the orbits, the amounts of energy are also quantized.

The lowest energy state of the electron in the hydrogen atom, and in any atom, is called the ground state. An electron may be raised from the ground state to an excited state if it is given an amount of energy from a source of heat, light, or electrical energy. If too much energy is supplied, the electron is stripped from its nucleus, and the atom is said to be ionized.

If we put some hydrogen gas in a glass tube at low pressure and then ionize it by passing some electrical energy through the tube, the hydrogen gas will emit visible light in addition to other wavelengths of radiation which we cannot see. This radiation is emitted when electrons in the hydrogen gas atoms lose the energy given them by the electricity and fall back toward the ground state. An excited electron does not remain long in the excited state, but loses the energy it acquired through a radiative process. Since the excitation energy has been absorbed in fixed amounts, the energy is reradiated in fixed amounts.

The wavelengths of the radiated light are therefore fixed and separated. Since there are different quantum levels to which electrons may be excited, the atoms of any one element may produce light at more than one wavelength, but each wavelength will be discrete. Since a different wavelength means a different color, we can, with the aid of a spectroscope, see that the light from hydrogen is really made up of a series of bright lines of different colors. This is true for any element which can be vaporized and then excited by electricity or heat.

Since the energy of photons radiated by the atom depends partially on the charge on the nucleus, and since by definition each element has a unique nuclear charge, then the atoms of each element will produce a set of bright lines at unique wavelengths. Every element may therefore be identified with the spectroscope by observing its emitted bright lines.

Activity II–5

THE NATURE OF PHOTON PRODUCTION

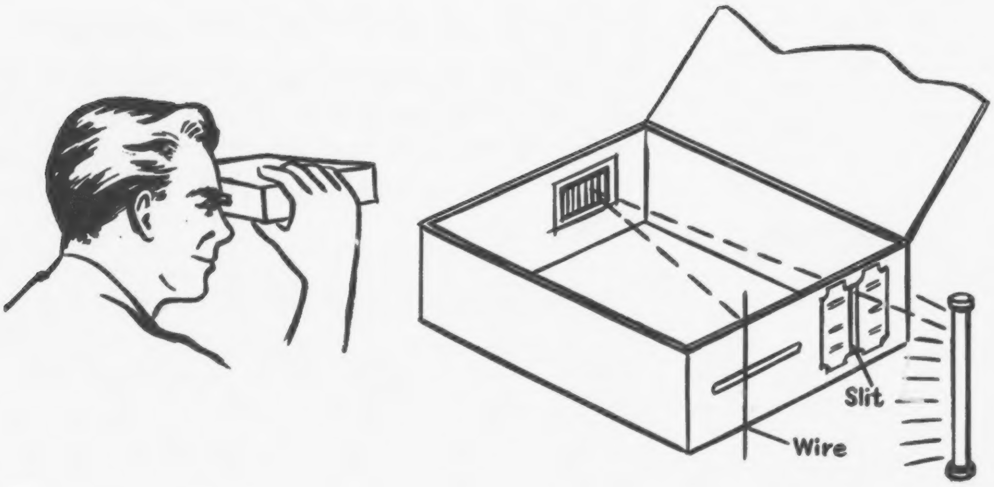
A useful, though inexact, analogy of photon production in the atom is the gain and loss of energy by an object which has been lifted and falls back to the Earth. According to the law of the conservation of energy, the exact amount of energy absorbed by the object when lifted up must be given off when it falls back. The amount of energy depends upon the mass of the object, the force of gravity, and the height of the object, or $E=Mgh$. The student should be required to calculate the potential energy of an object the same distance above the surface of different planets, the Earth, Moon, and so forth. The different gravity on each planet will produce a difference in the amount of energy. (See the table of Solar System Data in Unit IV.) This is roughly comparable to the different charge on the nucleus of atoms in an element. It must be stressed that in the atom the available positions of the electron are limited; therefore the energy is quantized.

Activity II–6

BUILDING A SPECTROSCOPE

Materials: Cigar box with cover, transmission diffraction grating, razor blades, six-inch length of thin copper wire, gas-discharge tubes, high-voltage source for exciting tubes

The grating should be fastened, with scotch tape or thumb tacks, over a rectangular hole cut in the front of the box. In the back a narrow vertical opening should be cut over which razor blades can be mounted to make a slit. A narrow horizontal opening should be cut so that the copper wire can be seen through it. When the grating and slit are lined up with an excited gas-discharge tube, an eye in front of the grating will see one or more spectrum lines, which appear to come from the back of the box. Holding the wire where the lines appear to be will make it possible for one to mark points, from which a scale in Angstrom units can be written along the horizontal opening on the back of the



box. To improve visibility, the user should close the cover while the spectroscope is in use.

Activity II–7

CALIBRATING THE SPECTROSCOPE

Using the numerical values below and some known gases (examples below), calibrate the spectroscope just constructed. The values are given in angstrom units. 1 Å = 10^{-8} centimeter.

Wavelength boundaries for color groups

Visible spectrum: 4000–7000
Violet: 4000–4240
Blue: 4240–4912
Green: 4912–5750 (maximum visibility at 5560)
Yellow: 5750–5850
Orange: 5850–6470
Red: 6470–7000

Typical representative values

Violet: 4100
Blue: 4700
Green: 5200
Yellow: 5800
Orange: 6000
Red: 6500

Some characteristic bright lines

Helium (He) : 5876, 4686, 6678, 4471
Hydrogen (H) : 4861, 6563, 4340, 4101
Mercury (Hg) : 4358, 5461, 5770, 5791

Make a scale on the window provided, labeling the colors and bright lines available in angstrom units.

Activity II–8

IDENTIFICATION OF UNKNOWN ELEMENT

Using the spectroscope just constructed, examine an unknown gas, and using the list below, identify the gas present. This will verify the accuracy of the calibrations on the spectroscope. If the spectroscope is calibrated accurately, it may now be used to study the spectra of the Sun, and so on.

The "unknown" should be one of the elements listed below. Values are in angstrom units and are taken from the HANDBOOK OF CHEMISTRY AND PHYSICS (45th edition). All are emission spectra. (Note: This activity may be postponed, if desired, until the discussion of stellar characteristics has been completed.)

Krypton (Kr) : 5570, 5871
Argon (A) : 6965, 7067, 7504
Fluorine (F) : 6856, 6902
Lithium (Li) : 3233, 4603, 6104, 6708
Strontium (Sr) : 4607, 4832, 4872, 4962
Neon (Ne) : 5401, 5833, 5853, 6402
Nitrogen (N) : 4100, 4110, 5667, 5676, 5680
Xenon (Xe) : 4501, 4624, 4671
Zinc (Zn) : 4680, 4722, 4810, 6362
Zirconium (Zr) : 4688, 4710, 4739, 4772, 4815
Scandium (Sc) : 4020, 4024, 5672

Activity II–9

IDENTIFICATION OF UNKNOWN ELEMENT

The students may use the spectroscope to identify the gases in neon signs. If a local supplier or repair company is located in the area, he may be willing to supply the signs and transformer, or the students may attempt to analyze the signs on commercial buildings in the area. Tubes with red color contain neon; tubes with blue color contain argon. All other colors are mixtures of these two gases with or without coated tubes. Occasionally mercury vapor is added for brilliance and may be identified as the same sequence of lines as in a standard fluorescent tube.

I. STELLAR SPECTRA

ANALYSIS OF STELLAR SPECTRA

Stars are emitters of light, so the spectroscope can be used to determine the elements present. When we analyze the spectra of most stars, including the Sun, however, we see a continuous spectrum with dark lines. The reason for this is stated in the following example:

> If one traps some sodium vapor in a bottle and then passes a spectrum of colors through the bottle, some of the yellow light will not pass through because the sodium atoms will have absorbed the yellow wavelength of light which corresponds to the energy that, by quantum mechanics, the electrons are permitted to absorb. The electrons do not store the energy, but radiate it in less than a millionth of a second. The reason one is able to see an absorption spectrum is that the reradiated energy comes out in all directions, whereas the exciting energy in the form of the beam of altered white light comes out in just one direction. The wavelengths of the dark lines are the same as the characteristic bright lines would be for sodium.

The data from the spectroscope tells us that the star is a hot gas under high pressure surrounded by a cooler, low-pressure atmosphere. But most important it tells us that the stars are made up of exactly the same elements that make up the Earth and that the same physical laws which govern the behavior of matter on Earth govern the behavior of matter in the stars.

SPECTRAL CLASSES

When the stars are scrutinized, it is found that different classes of spectra exist. The spectral classes are based on the visible presence of elements in certain ionization states which is dependent upon temperature. The main classes are, from hottest to coolest, O B A F G K M, which may be remembered by the phrase "Oh be a fine girl, kiss me." Each class is further subdivided into 10 subclasses designated by the numbers 0–9. The following table briefly lists some of each spectral class.

DRAPER CLASSIFICATION OF STELLAR SPECTRA

Spectral class	Example	Elements present	Temperature (°K)	Color
05	No bright star	H, He, O, N with electrons removed	50, 000	Blue-white
B0	Orion's belt	He at maximum intensity	21, 000	Blue
A0	Sirius	H maximum; Ca present	10, 600	Blue-white
F0	Canopus	Ca increases; other metals appear	8, 200	White
G0	Capella; Sun	Ca increases; other metals abundant	5, 500	Yellow
K0	Arcturus	Ca maximum; compounds appear	4, 500	Orange
M0	Antares	Compounds prominent	3, 200	Red

Trinklein and Huffer: MODERN SPACE SCIENCE. Holt, Rinehart & Winston, 1961. Used by permission.

J. THE HERTZSPRUNG-RUSSELL DIAGRAM

Hertzsprung and Russell independently plotted spectral type against luminosity in comparison with the Sun. The H–R diagram is a useful tool for displaying overall information about stars. The full meaning of the diagram will not be apparent until stellar interior is considered in Unit III.

The list below gives information about spectral class and absolute magnitude for a group of stars. These stars, identified by the numbers which indicate their order in the table, have been located on the following H–R diagram.

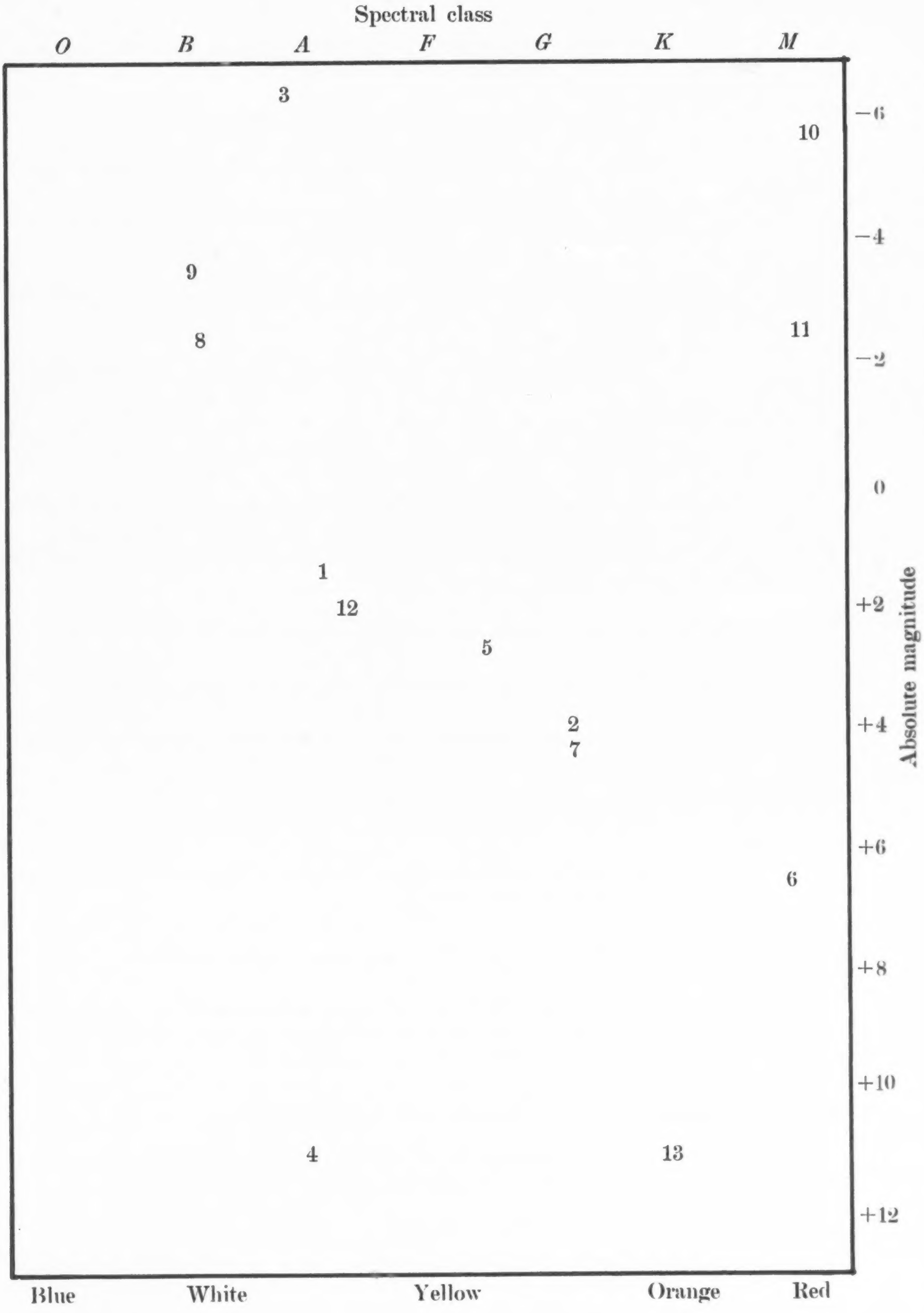
Star	Absolute magnitude	Spectral class
1. Sirius	+1.5	A1
2. Alpha Centauri	+4.1	G2
3. Rigel	−6.4	B8
4. Sirius B	+11	A0
5. Procyon	+2.7	F5
6. Epsilon Indi	+6.5	M0
7. Sun	+4.2	G2
8. Spica	−2.4	B1
9. B Crucis	−3.5	B0
10. Betelguese	−5.8	M2
11. Antares	−2.6	M1
12. Fomalhaut	+2	A3
13. Kruger	+11	K0

Activity II–10

THE H-R DIAGRAM

Set up a blank H–R diagram on the blackboard or overhead projector, and distribute blank H–R diagrams with several stars and their spectral classes and luminosities listed below the diagram. The students plot the stars on the diagram and then are asked what characteristics are related for main sequence stars.

Questions: Why are some cool stars very luminous? Why are some hot stars very dim? Introduce, by explaining the dependence of stellar brightness on size and temperature, the concept of red giants and white dwarfs. Stars plotted in the upper-right corner of the diagram are cool but very bright; they are therefore very large—red giants. Stars in the lower-left corner are hot but very dim; they are therefore very small—white dwarfs. The class may now search for the common denominator of the main sequence. Binary stars are discussed as a means of determining mass. Main sequence stars seem to have about the same mass. Stellar mass may be estimated through observations with the spectroscope.


Spectral class
O
B
A
F
G
K
M
3
10
9
8
11
1
12
5
2
7
6
4
13
−6
−4
−2
0
+2
+4
+6
+8
+10
+12
Absolute magnitude
Blue
White
Yellow
Orange
Red

SAMPLE QUESTIONS

1. How does the scientist distinguish between an element and a compound? A compound and a mixture?
2. What particles are contained in the nucleus of an atom?
3. What is the difference between atomic number and atomic weight?
4. Which experiment of Rutherford's caused him to construct the nuclear model of the atom? Describe the experiment.
5. What basic force in nature holds the electrons in orbit around the nucleus?
6. What basic force in nature holds the planets in orbit around the Sun?
7. What basic force in nature holds the atomic nucleus together?
8. What role do you think the neutrons play in nuclear stability?
9. List the types of waves in the electromagnetic spectrum from high to low energy.
10. Why do elements show unique wavelengths of light?
11. What exactly happens in the atom when it emits a photon?
12. What characteristics are used to distinguish between one spectral class of stars and another?
13. How can a star be intrinsically very bright and yet relatively cool?
14. Most stellar spectra are absorption spectra. What can you say about the structure of the star?
15. Why is the spectroscope a valuable tool in astronomy?
16. Why do compounds appear in the spectra of K and M stars and not in the spectra of stars belonging to other spectral classes? (See the table of spectral classes in Sec. I.)

PROBLEMS AND PROJECTS FOR FURTHER EXPLORATION

1. Take some common household items, such as milk, salt, nails, or ammonia, and prove whether each is a compound, element, or mixture.
2. Make a poster showing the characteristics of each spectral class with colored drawings of what you think a star of each class looks like.

3. With a star chart and reference book find the bright stars in the sky. After observing their colors, guess what the spectral class of each is. Then check your answer in the reference book.
4. The fact that most of the stars we can observe fall in the main sequence indicates that there is some factor which regulates their energy release. What could this factor be? Why?
5. Construct a mechanical model of the atom showing how a photon is produced.

AUDIOVISUAL AIDS

RADIO WAVES (27 min.) color McGraw-Hill Textfilms. Manmade and natural radio waves are discussed. Influence of the ionosphere on radio waves is explained. The relationship between radio waves, the ionosphere, the Earth's magnetic force, and solar activity is delineated. The new science of radio astronomy is described. An excellent film for the more advanced high school student.

CHEMICAL FAMILIES (21 min.) color Modern Learning Aids. Deals with the classification of elements. Atomic weights and numbers are examined and the periodic table is explained. This film is recommended for the advanced high school student.

EXPLORING THE UNIVERSE (11 min.) b/w Encyclopaedia Britannica Films. Describes the vastness of the universe and the complexity of motion going on in it. Examines stars and clusters showing their motion in relation to each other and as part of a great galaxy. Also touches on the theory of the expanding universe.

COSMIC RAYS (27 min.) b/w General Dynamics. Lecture by Bruno Rossi.

THE STRANGE CASE OF THE COSMIC RAYS (60 min.) color Bell Telephone Co.

LASER—THE LIGHT OF THE FUTURE (30 min.) color National Educational Television Film Service. Explains principles and first laser applications.

SPEED OF LIGHT (21 min.) b/w Modern Learning Aids. PSSC physics film.

SEAS OF INFINITY HQa 135 1969 (14½ min.) color National Aeronautics and Space Administration. Describes the Orbiting Astronomical Observatory (OAO), a series of orbiting telescopes used to study stars not visible from Earth. Features comments by leading scientists on the potential of this advancement in astronomy.

Addresses are listed in the Appendix.

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Baade, Walter (edited by Cecilia Payne-Gaposchkin) : EVOLUTION OF STARS AND GALAXIES. Harvard Univ. Press, 1963. Based on lectures given by Dr. Baade at Harvard. There is an orderly sequence from the types of stars and galaxies to their proposed evolution.

Baker, Robert H.: ASTRONOMY. D. Van Nostrand Co., Inc., 1964. Basic astronomy text.

Barnett, Lincoln: THE UNIVERSE AND DR. EINSTEIN. W. Sloane Associates, 1961. A well-written account of relativity recommended for teachers and advanced students.

Barrow, Gordon M.; et al.: PROGRAMMED SUPPLEMENTS FOR GENERAL CHEMISTRY. W. A. Benjamin, Inc., 1963. Excellent self-study guide for review of general principles of chemistry, including simple quantum mechanics.

Beiser, Arthur: THE FOUNDATIONS OF PHYSICS. Addison-Wesley Publishing Co., 1964. Discusses the wave nature of light. Includes a table of refraction.

Brant, John C.: THE SUN AND STARS. McGraw-Hill Book Co., Inc., 1966. Provides a good picture of the structure and evolution of stars.

Christiansen, G. S.; and Ganett, Paul: STRUCTURE AND CHANGE. W. H. Freeman Co., 1960. Excellent presentations on all phases of modern physics, chemistry, and some astronomy.

Davies, Rodney D., and Palmer, H. P.: RADIO STUDIES OF THE UNIVERSE. D. Van Nostrand Co., Inc., 1959. Covers optical astronomy, radio methods of observation, studies of radio sources, the radio universe, radio waves from the Milky Way, the Sun, and the planetary system.

Dull, Charles; Metcalf, H. Clark; and Williams, John E.: MODERN PHYSICS. Holt, Rinehart & Winston, 1963. Discusses alpha, beta, and gamma radiation. Describes the workings of the cloud chamber, linear accelerators, and cyclotrons. Also discusses half life and shows

the radioactive decay of uranium to lead with all intermediate products.

Fath, Edward A.: THE ELEMENTS OF ASTRONOMY. McGraw-Hill Book Co., Inc., 1955. Basic astronomy text.

Fermi, Laura: ATOMS IN THE FAMILY: MY LIFE WITH ENRICO FERMI. Univ. Chicago Press, 1954. An inspirational biography of the famous nuclear physicist.

Gamow, George: THE BIRTH AND DEATH OF THE SUN. New American Library, 1960. Discussion of stellar evolution and atomic energy in terms of the "big bang" theory.

Gamow, George: THE CREATION OF THE UNIVERSE. Bantam Books, 1960. The author describes his theories and includes two good chapters on stellar evolution and the synthesis of elements.

Gamow, George: MATTER, EARTH AND SKY. Prentice-Hall, 1965. Technical explanation of elastic waves and interference. Good diagrams.

Glasstone, Samuel: SOURCEBOOK ON THE SPACE SCIENCES. D. Van Nostrand Co., Inc., 1965. For the reader with an elementary knowledge of the conventional sciences, particularly physics and chemistry. Mathematics is minimal.

Glasstone, Samuel: SOURCEBOOK ON ATOMIC ENERGY. D. Van Nostrand Co., Inc., 1958. Compilation of material on the atom. Excellent for reference.

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2

learners. A wealth of simplified demonstrations, study questions, science vocabulary and project material.

Hoyle, Fred: ASTRONOMY. Doubleday & Co., Inc., 1962. Valuable for historical data and other illustrative material in all phases of astronomy.

Hoyle, Fred: FRONTIERS OF ASTRONOMY. Harper & Row, 1955. Presents a good picture of the steady-state theory.

Inglis, S. J.: PLANETS, STARS AND GALAXIES: AN INTRODUCTION TO ASTRONOMY. John Wiley & Sons, Inc., 1963. Basic astronomy text.

Jastrow, Robert: RED GIANTS AND WHITE DWARFS. Harper & Row, 1967. An interesting, thought-provoking book. Scholarly, yet easy to read. Presents a broad view of the universe. Of interest to students and teachers.

Ley, Willy: WATCHERS OF THE SKIES. The Viking Press, 1963. A history of astronomy from ancient times to today's unsolved space problems.

Massey, Harrie: SPACE PHYSICS. Cambridge Univ. Press, 1964. Requires a knowledge of calculus. Discusses the methods and procedures involved in the study of space; such as, radar and radio observations, infrared observations, and space vehicles for lunar studies and probes.

Massey, Harrie: THE NEW AGE IN PHYSICS. Basic Books, Inc., 1965. The newest discoveries in the world of the electrons and the nucleus as they relate to space science are covered. Contains numerous illustrations, photographs and mathematical proofs.

Mayall, Margaret: THE SKY OBSERVER'S GUIDE. Golden Press, Inc., 1959. Handbook for amateur astronomers, this useful book gives maps of the heavens, locations of planets, and names and descriptions of sky objects to observe.

McVittie, G. C.: Symposium of Problems of Extra-Galactic Research. The Macmillan Co., 1962. Compilation of papers presented at a symposium. The topics deal almost entirely with observational work in extra-galactic optical and radio astronomy.

Merrill, Paul W.: SPACE CHEMISTRY: Univ. Michigan Press, 1963. Since the accent in this book is on spectroscopy, the union of chemistry and astronomy in the search for information on the universe is detailed.

Messel, H.; and Butler, S. T.: THE UNIVERSE AND ITS ORIGIN. St. Martin's Press, Inc., 1964. Interstellar space, cosmic dust—formation and evolution of galaxies, evolution of stars and star clusters are described.

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Motz, L.; and Duveen, A.: ESSENTIALS OF ASTRONOMY. Wadsworth Publishing Co., 1966. Basic astronomy text.

Oldenberg, Otto: INTRODUCTION TO ATOMIC AND NUCLEAR PHYSICS. McGraw-Hill Book Co., Inc., 1961. Good reference detailing the methods by which the present knowledge in nuclear physics was acquired. Many experiments are described.

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Sears, Francis W.; and Zemansky, Mark W.: UNIVERSITY PHYSICS. Addison-Wesley Publishing Co., 1964. The book is based on Sear's three volume work, PRINCIPLES OF PHYSICS. The material covered includes electricity, magnetism, optics, and atomic physics. The emphasis is on physical principles. A complete set of problems appears at the end of each chapter. Many figures have been drawn to achieve greater uniformity and clarity. Numerous illustrative problems are worked out in the body of the text; in each, all physical quantities are expressed by numbers along with the appropriate units.

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Skilling, William T.; and Richardson, Robert S.: A BRIEF TEXT IN ASTRONOMY. Holt, Rinehart & Winston, 1966. Basic astronomy text.

Smoot, Robert C.; Price, Jack; and Barrett, Richard: CHEMISTRY, A MODERN COURSE. Teacher's edition. Charles E. Merrill Books, Inc., 1965. Logical development of chemistry. Suggested teaching aids and demonstrations along with interesting approaches.

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CLEAR PHYSICS. D. Van Nostrand Co., Inc., 1964. Clearly-written introduction to the physics of the atom.

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Beeler, Nelson F.; and Branley, Franklyn M.: EXPERIENCE WITH LIGHT. Thomas Y. Crowell, 1957. Presents experiments to test basic facts we know about light. Encourages the young reader to form his own hypotheses. Included are ways of measuring intensity, refraction, nature of light, wave theory, light and color, and so forth.

Bixby, William: THE UNIVERSE OF GALILEO AND NEWTON. American Heritage Publishing Co. 1964. Simple style and pictorial nature very appealing to children. Many interesting photographs, diagrams, and stories. Contributions of several astronomers and their applications clearly summarized.

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Elliott, Paul; and Wilcox, William F.: PHYSICS—A MODERN APPROACH. The Macmillan Co., 1960. Good illustrative material for development of laws of force and motion. Useful summary and conclusions at the end of each chapter, as well as suggested projects and additional reading list.

Fenton, C. L.; and Fenton, M. A.: WORLDS IN THE SKY. The John Day Co., 1963. Easy to read, elementary book on astronomy and rocket travel. The index gives a pronunciation guide.

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Gardner, Marjorie H.: CHEMISTRY IN THE SPACE AGE. Holt, Rinehart & Winston, 1965. Understandable and fully illustrated story of the organization of the atom.

Gregor, Arthur S.: A SHORT HISTORY OF THE UNIVERSE. The Macmillan Co., 1964. Tries to answer questions such as: Are there people living on other planets? Did a large chunk of Earth tear itself from the Pacific Ocean's basin and become our satellite, the moon? How old is a star and what is it made of?

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Hynek, A.; and Anderson, N.: CHALLENGE OF THE UNIVERSE. Scholastic Book Services, 1962. An introduction to the field of astronomy. Topics such as Earth, Moon, solar system, and stars are explained both descriptively and mathematically. Simple math formulas are used to explain various concepts in astronomy.

Jaffe, Bernard: MICHELSON AND THE SPEED OF LIGHT. Doubleday & Co., Inc., 1960. Presents an interesting, enlightening biography of the eminent scientist. Brief description of experiments which led up to Michelson's work.

Jastrow, Robert: RED GIANTS AND WHITE DWARFS. Harper & Row, 1967. An interesting, thought-provoking book. Scholarly, yet easy to read. Presents a broad view of the universe. Of interest to students and teachers.

Johnson, Russell H.; and Grunwald, Ernest: ATOMS, MOLECULES, AND CHEMICAL CHANGE. Prentice-Hall, Inc., 1966. Concepts in general chemistry written in easy-to-read style, important points italicized. Abundant illustrations, examples, and supplementary reading that make this informative and enjoyable.

Kiepenheur, Karl: THE SUN. Univ. Michigan Press, 1959. A good book for students who have a good background and interest in science.

Life Science Library: THE UNIVERSE. Time, Inc., 1962. Discusses early astronomers and fundamental properties of the universe in essay and pictorial form.

MacCracken, Helen: Decker, Donald; Read, John; and Yarian, Alton: BASIC PHYSICAL SCIENCE. The L. W. Singer Co., 1964. An excellent supplementary book for students and teachers. Factual, illustrative and contains demonstrations and student activities.

Marshall, Roy R.: SUN, MOON AND PLANETS. Holt, Rinehart & Winston, 1962. Paperback describing in simple terms the topic of measurement; includes descriptive chapters on the universe.

Mayall, Margaret: THE SKY OBSERVER'S GUIDE. Golden Press, 1959. This useful book gives maps of the heavens, locations of planets, and names and descriptions of sky objects to observe.

Moore, Patrick: THE BOY'S BOOK OF ASTRONOMY. Roy Publishers, Inc., 1958. A concise book with a review question section at the end. Covers the laws of physics and gives star mapping.

Moore, Patrick: NAKED-EYE ASTRONOMY. W. W. Norton & Co., Inc., 1965. An interesting approach to the study of astronomy because it helps the student to actually view the sky and find features and relationships, in addition to the constellations, without the aid of instruments.

Pfeiffer, John: FROM GALAXIES TO MAN. Random House, 1959. Excellent on galactic and stellar evolution leading up to and including evolution of life.

Richardson, Robert S.: ASTRONOMY IN ACTION. McGraw-Hill Book Co., Inc., 1962. Could be used to encourage a student to think of astronomy as a profession. It is filled with information written in an easy to read style.

Schroeder, W. Laurie: PRACTICAL ASTRONOMY, A NEW APPROACH TO AN OLD SCIENCE. Littlefield, Adams & Co., 1965. A useful book for locating stars and planets. Directions for constructing simple instruments to help in the identification of heavenly bodies are clearly given with many clear-cut diagrams.

Schulz, Richard W.; and Lagemann, Robert T.: PHYSICS FOR THE SPACE AGE. J. B. Lippincott Co., 1961. Fine illustration of principles and clear explanation of problems make this a useful student reference for modern physics.

Skilling, William T.; and Richardson, Robert S.: A BRIEF TEXT IN ASTRONOMY. Holt, Rinehart & Winston, 1966. Useful to students with limited background in science. Has clear diagrams, and is easy to outline.

Thompson, George: J. J. THOMPSON: DISCOVERER OF THE ELECTRON. Science Study Series. Anchor Books, 1966. Describes in detail the methods and apparatus used by Thompson to discover the electron. Includes photographs.

Thompson, George: THE ATOM. Oxford Univ. Press, 1962. Addressed to lay readers and concerned with fundamentals. Among the chapters included are structure of the nucleus, energy levels, and wave theory of matter.

Wilkins, Hugh P.: THE STARS. Prentice-Hall, Inc., 1954. Covers the stars in detail for the beginning student. Also gives information on other areas of astronomy.

Woodburn, John H.: RADIOISOTOPES. J. B. Lippincott Co., 1962. Explains the principles of isotopes in easy to understand language.

Addresses are listed in the Appendix.

Unit III

Unit III

ATOMIC NUCLEI AND STARS

UNDERSTANDINGS TO BE DEVELOPED

At the conclusion of this unit the student should have the following understandings:

1. The source of stellar energy
2. Nuclear fusion and the meaning of binding energy
3. The relationship between the cosmic abundance of elements and nuclear binding energy
4. The origin of stars
5. The interior of stars
6. Stellar evolution
7. The arguments supporting the cosmologies

A. THE ENERGY OF STARS

ENERGY SOURCES The stars release vast amounts of energy. Three possible mechanisms for producing this energy are gravitational collapse, chemical reactions, and nuclear reactions. If the first two were the source of energy for the Sun, which is a star, it would have burned out many millions of years ago. If maintained by the gravitational collapse theory, the Sun would a short time ago have had to be much larger than it is now. (The fossil record indicates that the amount of insulation of the surface of the Earth has been approximately constant for hundreds of millions of years.) The remaining possibility, nuclear reactions, may be used to explain the great energy release.

If one were to measure the mass of four protons separately and find that each had an approximate mass of 1.008 atomic mass units (AMU), and if he were somehow able to fuse these four protons, it would seem that the total mass of the product or products should be the same, 1.008 × 4 or 4.032 AMU. Under extraordinary circumstances this fusion has been performed on Earth with a very interesting result.

$$4\,{}_1H^1 \rightarrow {}_2He^4 + 2\,{}_{+1}e^0 + \text{Energy}$$

The four protons fuse to form one helium atom, composed of two neutrons and two protons, plus two positrons, plus energy primarily in the form of gamma rays. The interesting part of this reaction is that when the mass of the products is determined, it is found to be about 4.003 AMU; i.e., 0.029 AMU disappears. According to Einstein, the missing mass is converted into energy according to the relationship $E=mc^2$, where E is the energy, m the mass, and c the speed of light. Since the speed of light is a very large number, the equation tells us that a very small amount of mass may produce a vast amount of energy. In fact 1 kilogram of any substance can furnish the same amount of energy as could be obtained from burning 3×10^6 tons of coal.

Activity III–1

ATOMIC ENERGY AND THE SUN

Have the students calculate how much energy would be released if the teacher were completely converted to energy. Example:

$$\begin{aligned} E &= mc^2 \\ &= 100\ \text{kg} \times (3 \times 10^8\ m/\text{sec})^2 \\ &= 9 \times 10^{18}\ \text{joules} \end{aligned}$$

What is the mass equivalent in burning coal? The Sun releases energy at the rate of about 3.8×10^{26} joule/sec. How much mass loss per second does this represent? Rearranging the equation above,

$$m_{\text{kg}} = \frac{E\ \text{joules}}{c^2\ m/\text{sec}}$$

The mass loss per second is found to be approximately 4.2×10^9 kg/sec or about 5×10^7 tons. What is the mass loss in a year? The present mass of the Sun is about 1.98×10^{30} kilogram, and its current age is believed to be about 5×10^9 years. If the energy release has been constant during the lifetime of the Sun, what was its mass at the time of formation?

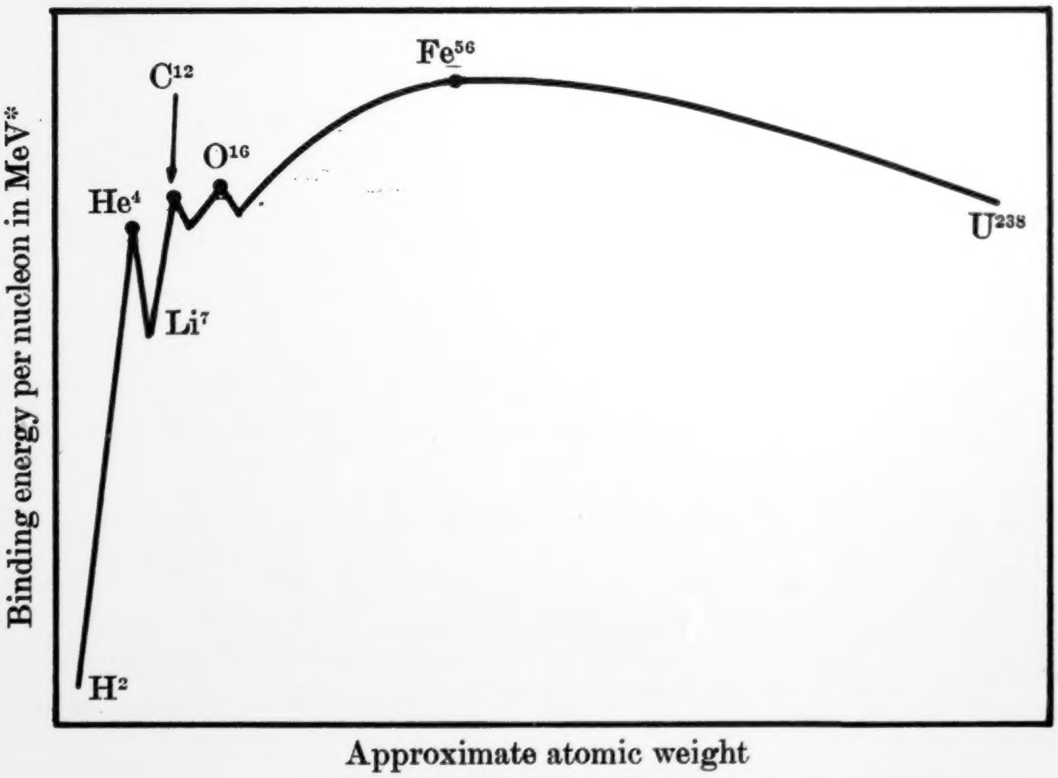
Mass at formation = present mass + (5×10^9 years × mass loss per year).

What percentage of the Sun's mass has been consumed?

B. BINDING ENERGY

BINDING ENERGY PER NUCLEON

The fusion of four protons is not the only possible energy-releasing nuclear reaction. There are many others. If, for example, we attempt to fuse the helium atom with an additional proton, we find that energy is absorbed, but if additional particles are fused to this growing nucleus, energy is released. In fact, as we proceed through the periodic table it seems that the energy-releasing nuclear reactions are those which build up atoms by atomic mass 4. This phenomenon exists until iron, atomic mass 56, is reached. Then all further buildup of atoms by the addition of particles (probably neutrons) is by energy-absorbing (endothermic) reactions. The energy released in exothermic nuclear fusion reactions is the same amount of energy which would be required to break the atoms apart and therefore is called the binding energy. The diagram provides a comparison of binding energy per nucleon.



*The electron volt (eV) is defined as the energy acquired by any charged particle carrying unit electronic charge when it falls through a potential difference of one volt. The MeV is equal to 10^6 eV and is called million electron volts. One atomic mass unit (AMU) is equivalent to 931 MeV if the mass were completely converted to energy.

Note that the binding energy per nucleon for the uranium atom is less than that of the iron atom; hence, if the uranium atom is split to form two fragments near to iron, energy will be released. This explains why the fission of certain atoms may release energy and why the fusion of others may also release energy. In both cases the product is farther up the binding energy curve than the reactants.

Activity III-2

NUCLEAR EQUATIONS AND BINDING ENERGY

The alteration of a nucleus by bombardment with particles may be visualized very easily by a simple game using marbles of two different colors. The students place a string in a circle on the floor to represent the boundary of the nucleus. One color, red for example, represents protons, and the other, black, represents neutrons. Using the periodic table and the appropriate number of red and black marbles, the students assemble a nucleus within the ring. Protons or neutrons are then shot into the nucleus and the resulting reactions are written in equation form. After writing the equation for the marble "nuclear reaction," the student can consult the binding energy graph to determine whether the reaction is exothermic or endothermic.

C. THE COMPOSITION OF COSMIC MATERIAL

TABLE OF ABUNDANCE OF SOME ELEMENTS IN THE COSMOS

The universe is filled with thin clouds of hydrogen in the space between stars. We know these clouds as dark objects in the Milky Way and by the interstellar absorption spectrum. Stars are composed of materials listed in the following table.

ABUNDANCE OF SOME ELEMENTS IN THE COSMOS

Elements	Symbol	Atomic weight	Abundance by number of atoms
Hydrogen	H	1	1
Helium	He	4	.14
Carbon	C	12	.0003
Nitrogen	N	14	.00009
Oxygen	O	16	.0007
Neon	Ne	20	.0003
Magnesium	Mg	24	.00003
Silicon	Si	28	.00003
Sulfur	S	32	.000004
Argon	A	40	
Iron	Fe	56	.000012
Germanium	Ge	73	15×10^{-9}
Silver	Ag	108	5×10^{-12}
Gold	Au	197	5×10^{-12}
Uranium	U	238	10^{-12}

The table of cosmic abundances was compiled from analysis of Earth, meteorites, solar spectra, stellar spectra, and interstellar absorption spectra. Abundances are given relative to hydrogen, which is represented by 1. The amount of matter in interstellar space is approximately equal to the amount of matter in stars. There are about 100 billion stars in the Milky Way galaxy and there are about 10 billion galaxies. Interstellar material is distributed nonuniformly by chance; atoms of interstellar matter have nothing to slow them down nor any force to make them fall.

Activity III-3

CORRELATION OF THE COSMIC ABUNDANCE OF ELEMENTS WITH BINDING ENERGY

(Why should certain elements be more abundant than others?)

Present the students with the table of abundance above and develop the problem. The elements not shown in the table are of very low abundance. If the students do not see the relationship between this table and the binding energy graph, then display the graph and ask them to list the elements that would release the most energy as fusion products. These are the elements at the successive peaks on the graph. The correlation between the binding energy of atoms and the abundance of atoms leads one to believe that atoms are or were built up in the universe from smaller atoms—probably hydrogen because of its great abundance.

D. THE FORMATION OF STARS

PROTON FUSION

For two protons or two nuclei to fuse, the particles must be moving toward each other at speeds high enough to overcome the electrical repelling force of like charges. At slower speeds, the reactants cannot come within the range of the strong, short-range nuclear force. When a gas is heated, the particles speed up in direct proportion to the increase in temperature. If a number of protons can be heated to a high enough temperature, and if they collide, they will fuse. If hydrogen fusion is the mechanism by which the stars produce energy, then we must account for the energy required to bring the initial mass of protons to a temperature high enough to cause the first fusion reactions. The following represents the current theory on star formation from the interstellar gas clouds and shows how the fusion reaction is started.

By chance, atoms of interstellar gas form clusters or clouds. The regions of condensation usually disperse into space before long. If the pocket of gas is large enough, gravitational forces between particles will hold the pocket together indefinitely and cause it to contract. With contraction will come collisions and a resultant increase in temperature. In 10 million years the temperature at the center of the shrinking sphere reaches 5000° C. At 5000° C collisions of atoms are violent enough to dislodge the electrons from the protons. The result is a spherical cloud composed of electrons and protons. With further contraction, the sphere shrinks to the size of a star and the temperature at the center rises to the critical value of 10 million degrees C. At a temperature of 10 million degrees C, protons are sufficiently energetic to move very close together even though electromagnetic forces of repulsion tend to keep them apart. When the protons move within 2 ten-trillionths of an inch of each other, very powerful short-range nuclear forces cause the protons to fuse into a single nucleus. The fusion releases vast amounts of energy.

The fusion of protons to form helium is the first stage in the history of a star. It takes place during about 90 percent of the star's lifetime. Initially stars are composed mostly of hydrogen; this hydrogen reacts by the proton-proton reaction or by the carbon cycle. The fusion of proton reaction begins when the kinetic energy (hence temperature) of the hydrogen nuclei is sufficiently high so that in collision the charge repulsion is overcome and the nuclei approach close enough to react. The proton-proton reaction consists of the following three steps:

a. ${}_1\mathrm{H}^1 + {}_1\mathrm{H}^1 \rightarrow {}_1\mathrm{D}^2 + {}_{+1}e^0 + \nu$ $+1.44$ MeV
b. ${}_1\mathrm{D}^2 + {}_1\mathrm{H}^1 \rightarrow {}_2\mathrm{He}^3 + \gamma$ $+5.49$ MeV
c. ${}_2\mathrm{He}^3 + {}_2\mathrm{He}^3 \rightarrow {}_2\mathrm{He}^4 + {}_1\mathrm{H}^1 + {}_1\mathrm{H}^1$ $+12.85$ MeV
ν = neutrino
γ = gamma ray
D = deuterium (heavy hydrogen)
${}_{+1}e^0$ = positron

The four-proton reaction stated at the beginning of this unit is a summation of the above reaction.

Demonstration III–1

PROTON FUSION AT HIGH VELOCITIES

(How do two protons overcome the repelling electrical force in order to fuse?)

Place two bar magnets on dowel rollers so that the north poles are facing each other. As one magnet is moved slowly toward the other, the repelling force pushes the other magnet away. If the first magnet is now pushed very rapidly toward the second they will make contact. This demonstration may be compared to the need for high velocities to fuse protons.

Demonstration III–2

FRICTIONAL HEATING AND GRAVITATIONAL ENERGY

Frictional heating may be easily demonstrated by having the students rub any two objects, including their hands, together. If this exercise is followed by a discussion of the reentry heating of spacecraft surfaces, it may be shown that gravitational energy may be converted to heat energy.

E. STELLAR STRUCTURE

COLLAPSE AND COOLING

The energy released by the fusion process is radiated. One-half of the gravitational energy of collapse that heats the material of a star is lost from a star by radiation. The center of the star becomes very hot, and the proton fusion reaction causes the production of gamma rays in the center. The gamma rays are absorbed by surrounding regions which are less hot and reemit X-rays; these are absorbed and reemitted by cooler regions as less energetic X-rays and ultraviolet rays; these are absorbed near the relatively cool surface of the star and reemitted as visible light (also ultraviolet and infrared). The star continues to collapse and furnish energy that is radiated until the temperature of the center reaches 10 million degrees C, at which time nuclear reactions begin and give off energy to maintain further nuclear reactions.

The energy release halts the further collapse of the star, which exists in a state of equilibrium between the outward pressure of the gas in the star by the release of nuclear energy and the inward force created by the force of gravity.

Hydrogen reactions continue until the hydrogen in the center of the star is converted to helium. This takes 10^{10} years for the Sun, 10^{7} years for a star 10 times more massive, and 10^{12} years for a star one-tenth as massive. The more massive star is shorter lived because the greater gravity must be balanced by a greater outward force and hence greater fuel consumption.

What occurs during the remaining 10 percent of a star's lifetime depends upon the size of the star. This will be discussed in the next section.

Demonstration III–3

THERMAL EXPANSION OF GASES

(Why does a star not completely collapse?)

Suspend a plastic cleaner's bag, with the hanged end closed, over a bunsen burner. The rising hot air will cause the bag to expand showing the thermal expansion of gases. That such thermal expansion can resist the forces of gravity may be demonstrated by letting go of the bag when it is filled. It will float to the ceiling. Although the forces involved in the flotation of the bag are somewhat different from those which prevent the collapse of the star, the demonstration is a dramatic means of illustrating the sustaining role of heat in the stellar model.

F. EVOLUTION OF STARS

RED GIANTS AND WHITE DWARFS

The first signs of stellar old age are swelling and reddening of the outer regions. This is the red-giant stage. As hydrogen is used up in the center and hydrogen reactions move slightly outward, the star expands as much as 60 times and the surface becomes cooler and hence redder. When a star's reserves of hydrogen fuel are exhausted, hydrogen reactions can no longer supply the energy for radiation, and stars less massive than the Sun collapse to the size of the Earth, radiating as white dwarfs until they finally cool and become dark. Stars more massive than the Sun collapse until the center temperature reaches 100 million degrees C. At this temperature helium has sufficient energy to react to form carbon. This process consists of two reactions:

$$
\begin{array}{ll}
{}_2\mathrm{He}^4 + {}_2\mathrm{He}^4 \rightarrow {}_4\mathrm{Be}^8 + \gamma & -95\ \mathrm{keV} \\
{}_4\mathrm{Be}^8 + {}_2\mathrm{He}^4 \rightarrow {}_6\mathrm{C}^{12} + \gamma & +7.4\ \mathrm{MeV}
\end{array}
$$

The column on the right indicates the energy released. A negative sign means that energy is absorbed in the reaction. The collapse then stops until the helium is consumed. Subsequently, when the helium fuel is exhausted, a second collapse and temperature increase occurs until the temperature reaches 300 million degrees C, at which temperature carbon nuclei react to form heavier elements. Contraction, heating, and nuclear synthesis continue until all the elements through iron are formed. Iron has the greatest binding energy per nucleon; therefore, iron cannot liberate energy in further nuclear reactions. The star then collapses, catastrophically rebounding in an explosion (supernova). In this explosion temperatures reach 5×10^9 degrees C. At this temperature the heavier elements through uranium are formed by neutron capture. All the material of the star is redistributed in interstellar space.

Demonstration III–4

NUCLEAR REACTIONS OF NUCLEI HEAVIER THAN HYDROGEN

(Why can heavy nuclei combine at higher temperatures only?)

The greater charge on the heavier nuclei means a greater speed is required to bring the nuclei together. The greater speed means a higher temperature.

Repeat *Demonstration III–1*, using electromagnets with a variable voltage source. As the voltage is increased a greater speed is required to bring the magnets together.

G. COSMOLOGY—THE UNIVERSE AS A WHOLE

As stars explode they spray forth elements which are drawn together to form a gaseous cloud and subsequently a new star. If this theory is correct, the universe can go on through the birth and death of stars until the basic hydrogen is consumed. There are about 100 billion stars in our galaxy (the Milky Way). The universe contains some 10 billion galaxies. This is estimated from sample counts taken in many regions of the universe. Galaxies appear to be randomly grouped.

THE COSMOLOGY PRINCIPLE

Over large-scale averages it appears that galaxies are distributed uniformly throughout the visible universe. The postulate that, indeed, the universe is uniform and galaxies are similar everywhere is called the cosmological principle.

THE RED SHIFT

When a railroad whistle passes, the pitch (frequency) seems to increase as the train approaches and then decreases as the train moves away. This change in frequency, known as the Doppler effect, also applies when a luminous body is approaching or receding. Light from an approaching object is shifted toward a higher frequency (blue), while light from a receding object is shifted toward a lower frequency (red). Thus, a red shift means that an object is moving away. When spectral lines from stars in distant galaxies are compared with spectral lines obtained from the study of elements in the laboratory, they appear to be shifted toward the red. The amount of shift is an indication of the velocity of recession. When the shift is to the red, so that the shifted velocity is less than the velocity of light, the velocity v of recession can be obtained from the following law of Doppler shift, where c is the velocity of light:

$$\frac{\text{Change in frequency}}{\text{Frequency}} = \frac{v}{c}$$

GALACTIC RECESSION It appears that all galaxies, on the average, are receding from each other with a velocity which is proportional to the distance between them.

IMPLICATIONS The use of the velocity-distance relationship suggests that all galaxies exploded from one place approximately 10 billion years ago. This figure can be compared with the age of the Sun, estimated to be 4.5 billion years, and the age of older stars, estimated to be 10 billion years.

Recently scientists working at Bell Laboratories have discovered the existence of radiation in the radio portion of the electromagnetic spectrum, which has the same intensity regardless of the direction in which the telescope is pointed. This radiation is believed to permeate the universe as the residue of a primordial explosion.

H. THEORIES REGARDING THE ORIGIN OF THE UNIVERSE

BIG BANG HYPOTHESIS The universe started as a very hot center of protons, electrons, and neutrons which subsequently expanded, cooled, formed into galaxies and stars, and continues to expand. Presently the universe is filled with radiation believed to be left over from the initial high temperature stage.

STEADY-STATE MODEL This assumes the perfect cosmological principle (that the universe is constant in time). As a consequence, to make up for the spreading of matter in the universe from the expansion, new matter is postulated to be created constantly. However, there have been recent discoveries of radiation which is believed to be a residue of the big bang. These discoveries of residual radiation (described in sec. G) tend to discredit the steady-state model.

PULSATING MODEL Some cosmologists envision a universe that can be oscillating forever between its condensed and expanded states. At the moment no scientific cosmology is satisfactory.

SAMPLE QUESTIONS

1. Prove that the Sun cannot be burning carbon as a primary energy source.

2. State the hydrogen fusion reaction.

3. Can you invent another energy releasing reaction?

4. Can you invent an energy releasing reaction involving Fe^{56}?

5. Where does the material for stars come from?

6. What happens in a star which causes it to evolve?

7. Why should we find many hot, blue stars imbedded in nebulae but not many in gasless areas of the galaxy?

8. What does the red shitt have to do with cosmology?

9. What prevents a newly formed star from collapsing by its own gravity?

10. Why does a star cool when it expands?

11. How does a supernova contribute to the formation of planets?

12. Why will nuclear fusion take place only at high temperatures?

13. What recent discovery has discredited the steady-state theory?

14. Give a general outline of stellar evolution.

15. If you saw two galaxies one of which had only red stars and the other of which had blue and red stars, which would you say was older? Why?

PROBLEMS AND PROJECTS FOR FURTHER EXPLORATION

1. Make a display with other members of the class on stellar evolution for the school library.

2. Investigate the abundance of elements on Earth and plot them against the binding-energy graph.

3. Do a research report on one of the cosmologies.

4. Trace an atom from the original hydrogen cloud to your hand.

5. Do research on the current work being done on controlling the hydrogen fusion reaction on Earth.

AUDIOVISUAL AIDS

UNIVERSE HQa 91 1960 (28 min.) b/w National Aeronautics and Space Administration. Explores by animation and special effects the solar system: Moon, Mars, Venus, Mercury, Earth, Saturn and on into the galaxies beyond the Milky Way. This is an excellent film for all high school students.

UNLOCKING THE ATOM (20 min.) b/w U.S. Atomic Energy Commission. Is designed to acquaint the students with the principles that govern the atom and its use. It describes chain reaction, atomic structure, and the properties of alpha, beta, and gamma rays and the operation of the cyclotron.

TRANSURANIUM ELEMENTS (23 min.) color Modern Learning Aids. A fairly advanced discussion of the manufacture and identification of elements 93 to 103, and the problems of placing them on the periodic table. Film should be a useful adjunct to the discussion of stellar creation of the elements.

UNIVERSE ON A SCRATCHPAD HQ 164 1967 (28 min.) b/w National Aeronautics and Space Administration. A candid portrait of a modern day astrophysicist, and his methods and objectives in studying the universe. Illustrates the work of Dr. Robert Jastrow and Dr. Patrick Thaddeus at the NASA Goddard Institute for Space Studies, New York City.

MADAME CURIE (20 min.) b/w Teaching Film Custodians. Excerpts from Metro-Goldwyn-Mayer biographical film of life and work of Madame Curie.

SEAS of INFINITY HQa 135 1969 (14½ min.) color National Aeronautics and Space Administration. Describing the Orbiting Astronomical Observatory (OAO), a series of orbiting telescopes used to study stars not visible from Earth. Features comments by leading scientists on the potential of this advancement in astronomy.

Addresses are listed in the Appendix.

TEACHER AND STUDENT BIBLIOGRAPHY

See teacher bibliography and student bibliography from Unit II.

Unit IV

Unit IV

THE SOLAR SYSTEM

UNDERSTANDINGS TO BE DEVELOPED

At the conclusion of this unit the student should have the following understandings:

1. The possible origin of the solar system
2. The characteristics of the Sun
3. The characteristics of the Moon
4. The characteristics of the planets
5. The characteristics of the Earth's atmosphere which permit the maintenance of life on Earth
6. Methods of dating the Earth

A. THE SOLAR SYSTEM IS BORN

COLLISION THEORY

There are two principal theories of the origin of the solar system. One theory proposes that the planets were formed as byproducts of a stellar catastrophe in which the Sun collided with a passing star. Gaseous filaments torn out of the two stars were attracted by the Sun's gravity and forced into orbit. The streams of hot gas condensed to form the members of the solar system other than the Sun. Since the likelihood of a collision between stars is very slight, there must be very few planets in the galaxy.

Recently several planets have been discovered circling around nearby stars. One of these stars is Barnard's Star: hour angle 17 hours 53 minutes, declination +4° 25 minutes, visual apparent magnitude 9.53, apparent motion 0.06 second of arc, period 1.1 years. The apparent motion of this star suggests the presence of an object or objects revolving about it, hence the assumption of either a twin star or a planet. In this case the invisible companion appears to be too small to be a star. Since the collision theory leads to the prediction that it is very unlikely for nearby stars to have encircling planets, the discovery of these planets casts doubt on the validity of the theory.

CONDENSATION THEORY

A second theory of the origin proposes that the planets condensed out of the cloud of gas and dust that formed the primitive Sun. This theory suggests that the formation of planets is a natural accompaniment to the birth of a star. Two reasons supporting this theory are that planets have already been detected around several neighboring stars and that the nearly circular orbits of the planets are in agreement with this theory.

In the condensation theory both stars and planets are formed by the gravitational contraction of a cloud of gas. If the mass of the collapsing cloud is great enough, high temperatures and resulting nuclear reactions will occur. If the mass of the collapsing cloud is small, temperatures will be too low for nuclear reactions to occur. The resulting body is a planet.

The difficulties with the condensation theory lie in the fact that it leads to the prediction that the Sun should spin on its axis at the rate of once every few hours. Acually the Sun turns on its axis once every 27 days. There is no convincing explanation for this lack of agreement. Additionally, according to the theory, the planets should contain a large fraction of the mass of the original solar cloud. Actually, the planets have only about one-thousandth of the mass of the Sun. Finally, it is difficult to understand how the individual atoms in the original gas cloud accumulated into larger bodies.

Activity IV–1

DISCUSSION OF FORMATION OF THE SOLAR SYSTEM

The students are asked to propose a theory of planet formation based on what they know about stellar formation. This may be a short in-class written exercise. Some of the theories are then read in class and the pros and cons are discussed. Included in the discussion should be the question of why nuclear reactions take place in stars but not in planets.

The students are then assigned the theories of solar system formation as a research project. The following day the theories are discussed in detail and again the pros and cons are discussed and the consequences of each theory are detailed. Finally, as a written quiz each student is asked to argue the case for the theory which he favors.

B. THE SUN

Our Sun is an average star of spectral class G2, with absolute magnitude 4.2. We know the broad outlines of its nature and formation. However, there is much specific information for which we are seeking.

The cause of solar flares is not known. It was formerly thought that the solar wind was present only for short periods of time following solar flares. We now know that the solar wind, consisting of plasma (charged particles), streams out constantly from the Sun at an average velocity of 500 km/sec. We do not know in detail the origin and composition of the solar wind.

The Sun has a magnetic field, the lines of which are pulled out by the solar wind into a form like an Archimedes spiral. The direction of the magnetic lines changes periodically. NASA has investigated solar phenomena through the use of the following satellites: Mariner, Pioneer, OSO, IMP, and Explorer.

C. THE MOON

The Moon and the other natural satellites around the planets were probably formed in the same manner as the planets but from smaller condensations. Only heavy atomic gases could remain trapped by the Moon's gravitational field (argon, molecular weight 40; xenon, molecular weight 131). Molecular gases like carbon dioxide (molecular weight 44) would be disassociated by ultraviolet radiation, and constituents would escape separately. No oceans are present, but there is evidence of some erosion that is probably caused by the impact of micrometeorites on the surface. The density of the Moon appears to be the same as the density of rocks in the Earth's crust. No magnetosphere has been detected about the Moon.

The average daytime temperature is 380° K, and the average nighttime temperature is about 120° K; sunset on the Moon takes 1 hour. The repeated temperature change indicates that heat is stored in the material of the lunar surface and that the surface material is a good insulator. This discovery has led to predictions that the material of the lunar surface is dust or porous rock. Closeup pictures of the lunar surface by a NASA soft-landing space vehicle have shown that the surface material is granular, not unlike soil on the Earth in consistency.

One of the most interesting features of the last three Surveyors was the use of an alpha-scattering experiment to chemically analyze the lunar surface. Alpha particles from a radioactive source are directed into the surface. Most of them are buried in the surface and do nothing. But some of them bounce back, reflected by the nuclei in the atoms in the surface. The experiment was designed so that an analysis of these reflections gave information about the composition of the lunar surface. A magnetized bar on the foot of the spacecraft also showed that some magnetic iron is found in the surface of the Moon. The lunar surface material appears to be primarily basaltic.

Surveyor and Lunar Orbiter spacecraft have provided extensive photographs of the lunar surface. These photographs have indicated to many scientists that there have been extensive lava flows on the Moon. Additionally, the pictures have revealed that the back side of the Moon is extensively cratered but that there are few maria compared to the side facing the Earth. The following is a list of NASA projects for exploration of the Moon:

Ranger IV, VI, VII, VIII, IX. Lunar photography

Surveyor I, III, V, VI, VII. Soft landing, determination of surface strength, analysis of chemical composition and magnetic properties of surface, lunar photography

Explorer XXXV. Lunar orbit, collection of data on magnetic and gravitational fields, solar wind, particles

Lunar Orbiter I, II, III, IV, V. Lunar orbit, lunar photography, selenodesy, detection of meteoroids, measurement of radiation

Apollo. Manned exploration of the Moon

Demonstration IV–1

THE MOON'S RELATIONSHIP TO THE EARTH AND SUN, AND LUNAR PHASES

Using a Sun-Earth-Moon planetarium model, or a blackboard drawing, the physical relationship of the three objects is illustrated and the proper scale is explained. The teacher then establishes the day-night line on the Earth and the direction of rotation of the Earth. The students should be able to show the noon and midnight lines on the Earth model, but problems may result in establishing the sunset and sunrise times. These may be cleared up by selecting a point on the turning Earth and showing that on one side the point goes from dark to light (sunrise 6:00 a.m.), and on the other side the point goes from light to dark (sunset 6:00 p.m.). With four time-reference points on the Earth, the Moon can now be placed in any position and the students may predict the time of rise, transit, and set. With the planetarium model or a sphere and light, the reason for the phase appearance may be illustrated.

Activity IV–2

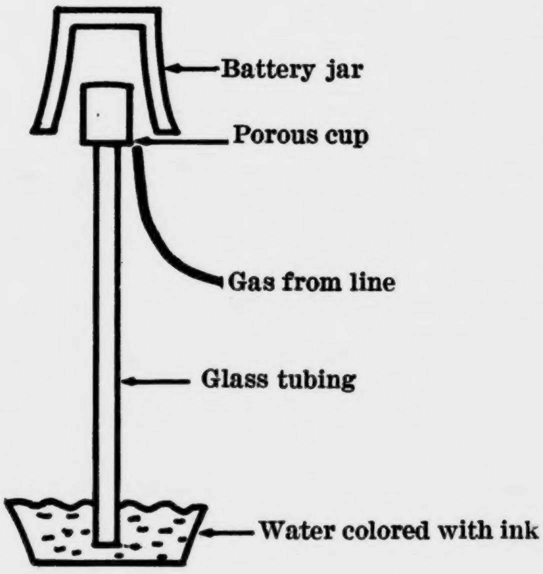
CONFIRMATION OF MOON PHASES AND TIMES

Selecting a day when the Moon is in the third quarter if the class meets in the morning, or first quarter if the class meets in the afternoon, the teacher has the class predict where the Moon will be in the sky and then takes them outside to observe the Moon. If the moon can be alined along two objects, its daily westward migration may be observed. Using a protractor, the approximate angular distance of 13° may be measured. From this information the length of the month may be calculated by dividing 360° by the measurement. Conversely, the extent of migration may be predicted by dividing the length of the month into 360°.

Demonstration IV–2

DIFFUSION OF GASES FROM LUNAR SURFACE

If two gases are at the same temperature, the molecules of the lighter gas will move faster and may achieve escape velocity for a celestial body. The diffusion rate of a gas is directly related to molecular speed. The reason for the departure of light gases from the surface of the Moon may be illustrated by the following demonstration.



Insert a one-holed stopper that has been fitted with a long piece of glass tubing into a porous cup. (You may wish to fasten a ruler, tape, or some other measuring device to the lower end of the glass tubing so that you can measure the height to which the liquid will rise in the glass tubing.) Fasten the porous cup so that the lower end of the glass tubing will be immersed in colored water. Attach a long piece of rubber tubing to a vent in the gas line where Bunsen burners are ordinarily attached. Hold a large battery jar over the porous cup. While you hold the end of the rubber tubing inside the battery jar, have someone else turn on the gas vent. What happens as the gas enters the battery jar? Bubbles emerge from the bottom of the tube. Turn off the gas and remove the battery jar. Now what happens? Water rises in the tube. How can it be explained?

CAUTION. The gas should be turned off as soon as possible. If possible, this experiment should be carried out under a hood or near an open window. Obviously all flames should be kept away from these gas mixtures.

Set up a hydrogen generator and repeat the experiment using hydrogen as the gas. Does the liquid rise as high when the hydrogen is removed from around the porous cup as when gas from the line was used? How do you account for the difference?

Demonstration IV–3

EROSION BY EXFOLIATION

The breaking up of rock on the surface of the Moon because of rapid temperature changes (exfoliation) may be illustrated by heating a piece of glass in a flame and then cooling it rapidly under cold water.

Demonstration IV–4

THE LUNAR SURFACE

Pictures of the lunar surface may be displayed to the students with the opaque projector and the different features discussed.

Activity IV–3

CALCULATION OF LUNAR CRATER DEPTH

In conjunction with *Demonstration IV–4*, the students may calculate the depth of craters if the scale of the picture and the Sun's angle are known. By measuring the length of the shadow, the height of the crater rim may be calculated by the tangent function of the Sun angle.

$$\tan \theta = \frac{\text{height of crater rim}}{\text{shadow length}}$$

D. THE PLANETS

Planetary data in the past have been acquired by observing sunlight reflected from the planetary surface, by infrared radiation emitted by the planets, and by radar echoes from the planets. There may be additional planets too small and too far from the Sun to be visible to us at this time. The scientific satellites of NASA have given us a new means of exploring the planets and have provided important new information.

MARS

Our best information about Mars was obtained through the mission of Mariner IV, which flew past Mars on July 14, 1965. It took pictures of the surface from distances of 7400 miles to 10,500 miles. The most arresting single phenomenon of the entire mission was the discovery of densely-packed, lunar-style craters on the Martian surface. The Moon-like appearance of Mars indicated that its surface is very old and apparently very little changed.

Atmospheric pressure on Mars is much lower than was believed, and is from 0.4 percent to 0.7 percent of Earth's pressure at the surface. Carbon dioxide is probably the major constituent. The proportion of nitrogen is very small. This thin blanket of air correlates with the cratered appearance of Mars, since a dense atmosphere might have shielded the planet from most of the meteoritic impacts. No magnetic field or radiation belt was detected.

VENUS

Information about Venus has been obtained by two NASA satellites, Mariner II, which came within 21,648 miles of Venus on December 14, 1962, and Mariner V, which swept within 2544 miles on October 19, 1967. The primary objective of the Mariner V mission was to obtain information about the atmosphere, ionosphere, and plasma environment of the planet.

Contrary to romantic ideas about the planet, Venus has a hostile, desert environment. The surface temperature may be as high as 400° C. or more, higher than the melting point of lead. The atmosphere is believed to consist of from 69 percent to 87 percent carbon dioxide, with the other major constituent being nitrogen. There appears to be no oxygen. The atmospheric pressure is seven or eight times as great as the Earth's pressure. The dense Venusian atmosphere is believed to act as a lens, refracting light and radio waves so that they circle the planet and may even return to where they started. Thus if a person could stand on the surface, he might see his own back in front of him. The horizon might seem to be above him, so that he would seem to be standing in a depression. There may be no nighttime darkness on Venus because the atmosphere bends sunlight around the planet.

Some scientists think that the dense clouds around Venus are composed mostly of volcanic dust. Radar and telescopic studies indicate that the atmosphere rotates about 50 times as fast as the planet itself, so that its surface is constantly lashed by scorching winds. Venus has an ionosphere, which is weak at night and strong during the day. It is surrounded by a shock wave, like the Earth's magnetosphere, resulting from the impact of the solar wind on the ionosphere. If Venus has a magnetic field, it is not stronger than 1/300 that of the Earth.

SOLAR SYSTEM DATA

Planet	Diameter (Earth=1)	Average radius of orbit (AU)	Sidereal period (Years)	Period of rotation (Days)	Surface gravity (Earth=1)	Surface temperature (°K) Sunlight	Surface temperature (°K) Dark
Mercury	0.38	0.39	0.24	88	0.38	611	
Venus	.97	.72	.62	260	.87	700	240
Earth	1	1	1	1	1	295	
Mars	.53	1.5	1.9	1	.39	260	
Jupiter	11	5.2	12	.41	2.65	128	135
Saturn	9.0	9.5	29	.43	1.17	125	93
Uranus	3.7	19	84	.44	1.05	103	
Neptune	3.4	30	165	.66	1.23	108	
Pluto	.45	39	248	6	?		

SOLAR SYSTEM DATA

The above table gives the physical data that we have at present about the solar system. The giant planets, Jupiter and Saturn, are believed to have dense atmospheres. The atmospheres of Mercury and Pluto, if they exist, are probably very thin. Neptune and Uranus are believed to have atmospheres, but little is known about them.

A question remaining uppermost in one's mind is whether or not the planets are habitable. To answer this question, one must first look at what makes the Earth habitable. The following three properties of the Earth's atmosphere are essential to the maintenance of life on Earth.

CONDITIONS FOR LIFE ON EARTH

Greenhouse effect: The presence of the Earth's atmosphere results in an increase in the average temperature of the Earth from −20° C average, if there were no atmosphere, to +20° C. This makes the difference between the present comfortable climate of the Earth and a climate in which most of the Earth's water would be always frozen. The reason for this heating of the Earth is that the Earth's atmosphere freely passes the energy carried by visible light from the Sun, while the carbon dioxide and water vapor in the Earth's atmosphere partially block the reradiation of the infrared wavelengths from the Earth's surface.

Water vapor trap in stratosphere: The temperature of the Earth's atmosphere reaches a minimum of −70° C at 10-kilometer height (the tropopause) causing water vapor to freeze to ice crystals. This prevents the diffusion of water vapor to higher levels where water molecules would be dissociated by the intense ultraviolet radiation allowing the freed hydrogen gas to escape from the Earth's atmosphere into space.

Absorption of ultraviolet radiation in and above the stratosphere: Intense ultraviolet radiation that would be lethal to life is largely absorbed in and above the stratosphere, by molecular dissociation and ionization.

Activity IV–4

CHARACTERISTICS OF THE PLANETS

The students are given the distances and sizes of the planets in table form. The following columns are left blank and the students are required to fill them in: surface temperature, surface gravity relative to Earth, atmosphere (yes or no), and period of revolution around the Sun. The students cannot enter absolute values, but may use relative values. The hypotheses of the students are then discussed and it is brought out that in order to study the planets, the Earth must be studied. The activity also shows the student that such basic characteristics as size and distance from the Sun may be used to predict additional characteristics of the planets.

Demonstration IV–5

THE GREENHOUSE EFFECT

A box of dark soil with a thermometer thrust into it is covered with a piece of glass. A strong lamp is then shone on the box or the box is placed in the sunlight until the temperature stabilizes. A second box with thermometer, but no glass, is placed in the light. The temperature of the second box will stabilize at a lower temperature because the infrared radiated by the soil in the first box is trapped by the glass.

Activity IV–5

THE EFFECT OF ULTRAVIOLET LIGHT ON LIVING THINGS

The students prepare bacteria cultures on petri dishes. Half of the cultures are irradiated with ultraviolet light and the other half are kept as controls. Following the exposure to the ultraviolet light, growth measurements are taken of both sets of colonies. The effect of ultraviolet light on living things may be illustrated and the importance of our atmosphere discussed. It is ozone in the chemosphere which is primarily responsible for absorption of the ultraviolet light. It is interesting to note that the presence of ozone (O_3) in the atmosphere is caused by the presence of molecular oxygen (O_2), which is a product of photosynthesis in green plants.

EARTH'S MAGNETOSPHERE

Some scientists believe that a magnetic field, or magnetosphere, may be necessary for the development of the higher forms of life. A continuous stream of charged particles, known as the solar wind, flows out continuously from the Sun at a speed of approximately 1 million mph. When it strikes the boundary of the magnetosphere, about 40,000 miles from the Earth on the Sun side, a shock wave is created and the wind divides to flow around the magnetically protected cavity containing the Earth. The magnetosphere is blown out into space approximately 3.5 million miles beyond the Earth into a thin teardrop shape. This protection from high-energy solar particles may have been necessary for the evolution of higher forms of life on Earth.

Data about the magnetosphere has been obtained from numerous NASA satellites, including OGO I, Explorers XVIII and XXXIII, and especially from Pioneers VI and VIII.

E. DATING THE EARTH

RADIOACTIVE DECAY

The atoms of certain elements contain unstable nuclei which spontaneously emit particles or rays. This phenomenon is called radioactivity.

Sodium ${}_{11}Na^{23}$ is the naturally occurring isotope of sodium. Sodium ${}_{11}Na^{24}$, another isotope, is unstable. In time, it emits another particle, an electron. This electron has nothing to do with the atomic or orbiting electrons, nor did it exist within the nucleus until it was expelled. ${}_{11}Na^{22}$ is also unstable. In time, it will eject an antielectron or positron, which is just like an ordinary electron except that it has a positive charge. ${}_{11}Na^{23}$ is the only stable isotope of sodium.

Oxygen has three stable isotopes, ${}_8O^{16}$, ${}_8O^{17}$, and ${}_8O^{18}$. The abundances of these isotopes are 99.759, 0.037 and 0.204, respectively. ${}_8O^{15}$ is radioactive and emits a positron. $_8O^{19}$ is also radioactive and emits a beta particle, which is just an ordinary electron emitted from the nucleus. Some nuclei do not emit particles when they undergo radioactive processes. For example, $_{82}Pb^{200}$, an unstable form of lead, emits electromagnetic radiation in the form of gamma rays.

Radioactive decays are written in equation form, since the element that decays often does not stay the same. Here are some examples:

$$_{11}Na^{24} \xrightarrow{\text{15 hours}} {}_{12}Mg^{24} + {}_{-1}e^{0}$$

which means that sodium 24 decays into magnesium 24 and a beta particle, which is emitted. Fifteen hours is the measure of the half life of $_{11}Na^{24}$. If 1 pound of sodium 24 is present now, in 15 hours one-half pound will be present. One-half pound of magnesium 24 will also be present.

$$_{92}U^{238} \xrightarrow{4.5\times10^{9}\text{ years}} {}_{90}Th^{234} + {}_{2}He^{4}$$

Uranium decays into thorium and an alpha particle, or helium nucleus. Again, the alpha particle did not exist in the nucleus, but was created at the time of decay. Thorium 234 is also unstable. There are 14 additional decays until the 15th daughter element is reached. This is lead 206, which is stable.

The sum of the atomic weights before decay is slightly more than the sum of the atomic weights after decay. The slight loss in weight accounts for the fact that the smaller decay particle comes shooting from the nucleus with significant kinetic energy. Some of the mass of the original nucleus is converted into the energy of motion.

An unstable or radioactive nucleus must eventually decay. However, the radioactive forms of element Q are not necessarily as unstable as the radioactive forms of element L. It is true, therefore, that if equal quantities of L and Q are made now, in 1 year 90 percent of L may have decayed, whereas only 2 percent of Q may have decayed.

HALF LIFE

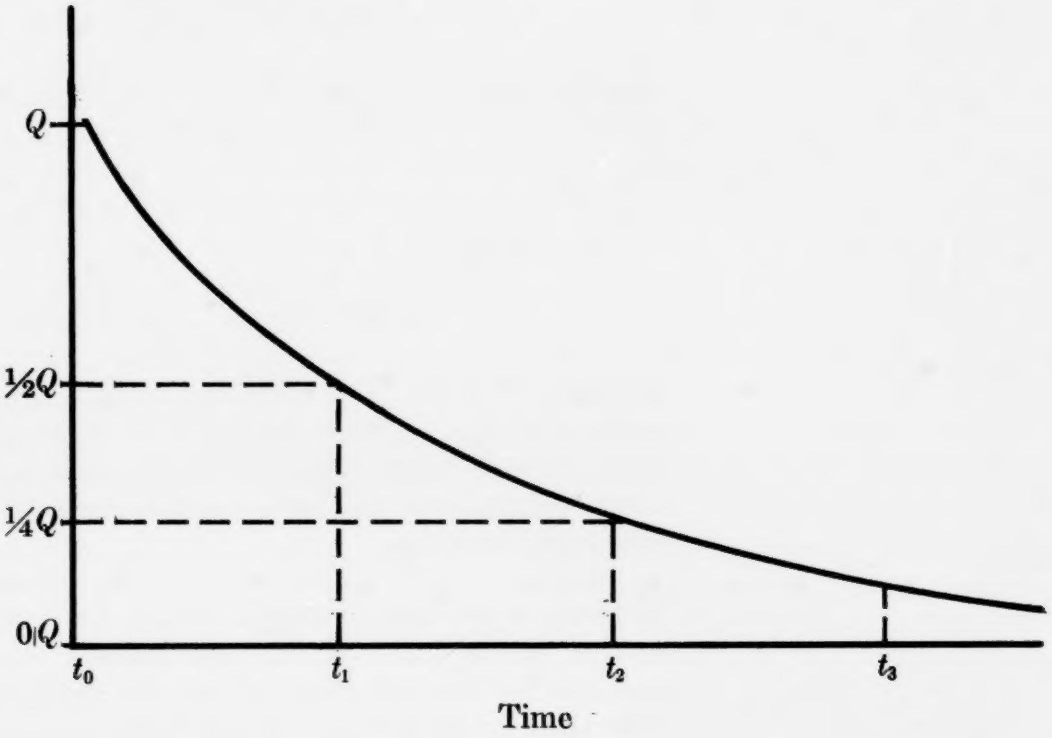
The length of time it takes for a quantity of an unstable element to decay is determined by its half life, which can be determined by laboratory measurement.

The half life of Na^{24} has been given as 15 hours. If 10 tons are made now, about 5 tons will remain after 15 hours, 2½ tons after another 15 hours, and so on. After a very long time, most of the original Na^{24} will have decayed to magnesium.

It is impossible to predict exactly when a given unstable nucleus will decay. Since the half-life figures are based on a statistically enormous sample, within which there is a distribution of values, it may be that, in a sample of sodium 24, a certain nucleus will decay in 10^{-7} seconds and another nucleus will decay in 10^{7} years. The probability of either of these decay times is very low for an element with a half life like that of sodium 24. The value of the half life is the most probable lifetime.

The following graph shows the simple relationship between time and the original quantity of a substance, here labeled Q.

HALF-LIFE DECAY



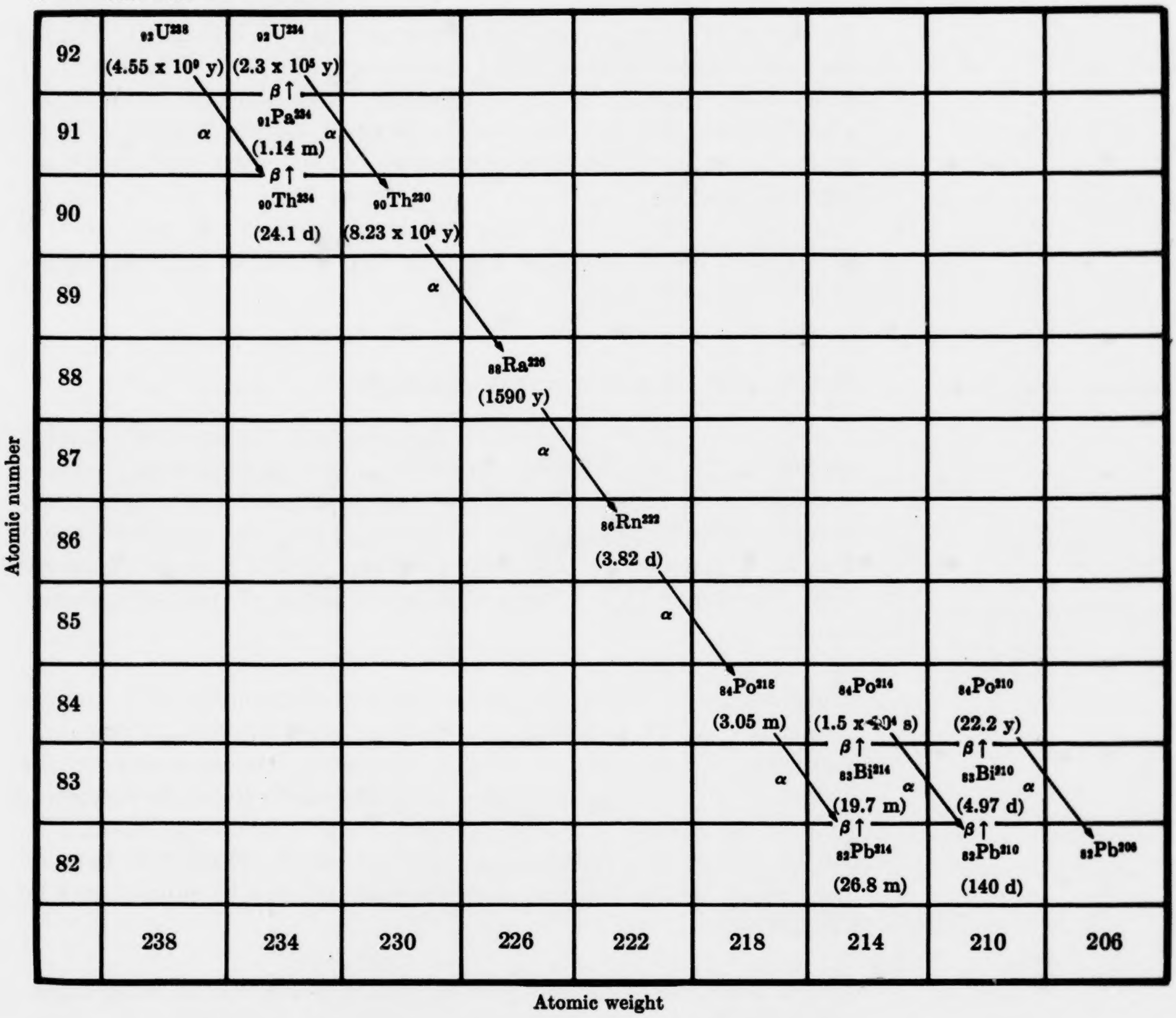
$t_1 - t_0 =$ half life

$t_2 - t_1 =$ half life

The discovery of radioactivity, and the half-life decay concept, has provided man with the tools for very accurately determining the age of the Earth.

The oldest crystal rocks dated by the uranium lead decay technique are 3.3 billion years old. Uranium and thorium dating depends on the radioactive decay of uranium or thorium into lead via a radioactive series. The series for ${}_{92}U^{238}$ is illustrated below. The half lives are expressed in years (y), days (d), minutes (m), and seconds (s).

RADIOACTIVE SERIES



Atomic number
92
91
90
89
88
87
86
85
84
83
82
$_{92}U^{238}$
(4.55×10^9 y)
$_{92}U^{234}$
(2.3×10^5 y)
$\beta \uparrow$
$_{91}Pa^{234}$
(1.14 m)
α
α
$\beta \uparrow$
$_{90}Th^{234}$
(24.1 d)
$_{90}Th^{230}$
(8.23×10^4 y)
α
$_{88}Ra^{226}$
(1590 y)
α
$_{86}Rn^{222}$
(3.82 d)
α
$_{84}Po^{218}$
(3.05 m)
$_{84}Po^{214}$
(1.5×10^{-4} s)
$_{84}Po^{210}$
(22.2 y)
$\beta \uparrow$
$\beta \uparrow$
α
$_{83}Bi^{214}$
α
(19.7 m)
$_{83}Bi^{210}$
α
(4.97 d)
$\beta \uparrow$
$\beta \uparrow$
$_{82}Pb^{214}$
(26.8 m)
$_{82}Pb^{210}$
(140 d)
$_{82}Pb^{206}$
238
234
230
226
222
218
214
210
206
Atomic weight

The age determination depends on measuring the relative amounts of various uranium and thorium isotopes in a rock by chemical and mass spectroscopic means. After correcting for the expected amount of various isotopes of primordial lead, the ratio of uranium parent to lead daughter isotopes indicates the time since the crystallization of this rock. The half lives of uranium and its decay products are given in the table. Most lead appears to be radiogenic (of radioactive origin). In this way, the oldest rocks on the Earth are measured to be 3.3×10^9 years old. The oldest meteorites are 4.6×10^9 years old. This age is assumed to represent the age of the Earth and solar system.

Activity IV–6

THE CLOUD CHAMBER

By the use of a cloud chamber the students may be shown that particles are in fact speeding away from radioactive substances. There are very inexpensive commercial cloud chambers with sources available for which alcohol and Dry Ice must be obtained. Full instructions accompany the device. This is a dramatic way of presenting radioactivity to the students. Most tracks seem to emanate from the source, but occasionally a track will be observed which comes from quite another direction. This is probably a cosmic ray which is bombarding the Earth from outer space.

Demonstration IV–6

PROPERTIES OF RADIOACTIVE EMISSION

The Geiger counter is placed in operation and the students' watches are checked for radioactivity. A problem may arise since some luminous watches are not radioactive. (If the students do not know why some are not, an excellent investigation activity may be developed at this point.) The basic operation of the Geiger counter should then be explained and compared with the cloud chamber in terms of indirect measurement.

The Geiger tube is then mounted at one end of the meter stick, and the radioactive source is placed at a distance from the tube, which gives a greater than midpoint reading on the meter. Various substances are placed between source and tube, including one's hand, to determine penetration of particles. The hand will absorb all beta radiation. This can be proved by inserting an additional hand, which will have no great effect on the reading. A rough ratio of beta to gamma may be calculated.

At this point, the students can measure background radiation by counting clicks for several minutes and measuring by counts per minute. (If the school Geiger counter is equipped with earphones only, an amplifier may be added by using a lead with a male plug on each end. One end is plugged into the earphone output of the Geiger counter, and the other into the input of a tape recorder or an amplifier. This procedure is easily within the capability of a school audiovisual department.)

Sufficient shielding to eliminate beta radiation is then placed between the source and tube. A reading is taken at the original distance *d*, subtracting background. This is tabulated on the blackboard and the students are asked to predict the reading 2*d*, 3*d*, and 4*d*. The reading is then taken at each distance and tabulated. Two or three trials should be made. The data will confirm the inverse-square law. It is advisable to know before class: What count or dose is dangerous to humans? What count or dose is lethal to humans? How is radiation damaging to living tissue?

Activity IV–7

SIMULATED DETERMINATION OF HALF LIFE

Determination of the half life of an actual radioactive isotope requires such large amounts of expensive equipment that it is prohibitive in most high schools. However, the following activity provides the students with a model of the half-life determination procedure and a challenging problem.

Before class the teacher mixes by weight iron filings (atomic weight 56) and sodium chloride (molecular weight 58.5) so that the ratio of Fe to NaCl is approximately some integral power of 2. The students are then given the imaginary situation that salt decays into iron and that the resulting mixture was pure salt *T* days ago. The problem is to determine the half life of salt. The difference in weight may be said to be caused by the departure of particles. The students must separate the "isotopes" using a property that one has and the other does not. They then must determine the half life. Iron can be separated from the salt with a magnet or the salt may be separated from the iron by dissolution and evaporation.

An alternate plan is to assign a half life to salt and ask the students to determine the age of the rock that is now composed of salt and iron. The problem may be further complicated by the addition of sand as an inert substrate.

MEASURING RADIATION WITH SATELLITES

Nearly all scientific satellites launched by NASA have carried instrumentation for the detection of radiation. Among the various kinds of radiation detectors are the following basic types: Geiger-Müller counter, proportional counter, ionization chamber, channel multipliers, scintillators, Cerenkov detectors, cadmium sulfide cells, and solid-state detectors. The first detector used was the Geiger-Müller counter. From these basic types have been developed numerous detector combinations.

F. USE OF FOSSILS TO CONFIRM THE AGE OF THE EARTH

Fossils consist of the remains, petrified remains, or petrified impressions of organisms that lived in the distant past. They are generally found in sediments or sedimentary rock, and they are useful to the geologist in dating the strata in which they are found or in confirming a date that has been obtained by radioactive means. Fossils have also provided almost all of the information that we possess about evolution.

Demonstration IV–7

FOSSILS

Display fossil remains for the students to observe and, if possible, to handle. If a series of fossils showing the evolution of an organism can be obtained, the display will be all the more valuable.

Activity IV–8

METHODS OF FOSSIL EXTRACTION

Have the students bring in a glass jar about one-quarter full of sand. Place some water and cement in each jar, and when the student has thoroughly mixed the three components, have him place a shell in the middle of the mixture. Allow the concrete to dry over the weekend, and then place each jar in a bag and fracture the glass with a hammer. The "rocks" that remain are then traded by the students, and each is asked to take his home and extract the "fossil" intact. This activity gives the student an idea of the techniques used by the geologist.

SAMPLE QUESTIONS

1. Defend the condensation theory of planetary formation.
2. Give reasons for and against the collision theory of planetary formation.
3. Why does the United States send men to explore the Moon?
4. Describe the lunar surface.
5. What have recent lunar probes discovered about the Moon?
6. What planet, other than the Earth, appears to have the most favorable characteristics for life?
7. Why should Jupiter be considered as a possible habitat for living things?
8. What three factors in the Earth's atmosphere, other than composition, permit life to continue on Earth.
9. What three particles or rays are the most common radioactive emissions?
10. Explain how scientists use radioactive materials to date rocks.
11. How are fossils used to date rocks?
12. What is the meaning of half life?
13. What type of scientist would you send on a mission to Mars?
14. What kind of erosion may have taken place on the surface of the Moon?
15. What kind of erosion takes place on the surface of the Earth?

PROBLEMS AND PROJECTS FOR FURTHER EXPLORATION

1. Do research in your school and public library on the geologic history and age of your town or area.
2. Plan a lunar exploration expedition detailing personnel and equipment.
3. Consult your local newspaper for the position of the planets in the sky, then observe them with a small telescope.
4. Make a chart showing the time of rise, transit, and set for each phase of the Moon.
5. With the help of your teacher set up a cloud chamber and camera to take pictures of particle tracks.

AUDIOVISUAL AIDS

LONG TIME INTERVALS (25 min.) color Modern Learning Aids. A discussion of the significance of long time intervals with a detailed description of radioactive dating arriving at an estimate for the age of the Earth. Excellent film for the average and above-average high school student.

THE SOLAR FAMILY (11 min.) color Encyclopaedia Britannica Films. An introductory study of the planets—their evolution, motions, sizes and satellites. It describes with animated drawings the evolution of the solar system according to the planetesimal hypothesis and traces the real and apparent motions of the planets. The planetoids, Halley's comet, and the movement of the solar system are also described. Excellent film for all high school students.

PLANETS IN ORBIT—THE LAWS OF KEPLER (10 min.) b/w Encyclopaedia Britannica Films. Traces a brief history of man's earliest observation and beliefs about the universe. Goes on to show how Kepler made three discoveries that revolutionized astronomy. Kepler's three laws are visualized in animated sequences. Excellent film for all high school students.

THE EARTH IN MOTION (11 min.) b/w Encyclopaedia Britannica Films. Portrays the Earth as an astronomical body, its relation to the Sun and its motions. It presents evidence of the Earth's spherical shape, axis rotation, revolution, and inclination of its axis. Explains the causes of day and night and the change of seasons. This is a good film for all high school students.

THE INTERIOR OF THE EARTH (14 min.) color or b/w McGraw-Hill Textfilms. Several clever demonstrations are used to explain how scientists have learned much about the construction of the Earth's interior from seismic wave data. Introductory level.

VIEW OF THE SKY HQ 163 1967 (27 min.) color National Aeronautics and Space Administration. An explanation of the various historical theories of the solar system from Copernicus through Einstein, with a brief look at present day space exploration. Illustrated with symbolic photography and effects, the story is told from a young boy's point of view.

STEPS TO SATURN HQa 67 1962 (22 min.) color National Aeronautics and Space Administration. Depicts the background and development processes of the Saturn program. Shows the flight of the first Saturn launch vehicle.

ASSIGNMENT: SHOOT THE MOON HQ 167 1967 (28 min.) color National Aeronautics and Space Administration. A dramatic portrait of the Moon as seen through the best of thousands of photographs taken by the Ranger, Surveyor, and Lunar Orbiter spacecraft. This film illustrates the complexity of getting detailed pictures of the Moon, and summarizes what man has learned about the Moon and how this new knowledge will aid manned lunar landings. The viewer travels across the surface of the Moon to examine in detail its features, its soil, and the unseen side of Earth's nearest neighbor.

THE VAN ALLEN RADIATION BELTS—EXPLORING IN SPACE (17 min.) color Encyclopaedia Britannica Films.

Addresses are listed in the Appendix.

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Beiser, Arthur: THE EARTH. Time, Inc., 1962. Well-illustrated book with pictures of rocks, landscapes, crust of Earth, anatomy of skies.

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Glasstone, Samuel: SOURCEBOOK ON THE SPACE SCIENCES. D. Van Nostrand Co., Inc., 1965. Intended for the reader with an elementary knowledge of the conventional sciences, particularly physics and chemistry. Mathematics is minimal.

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Addresses are listed in the Appendix.

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Addresses are listed in the Appendix.

Unit V

Unit V

THE ORIGIN AND EVOLUTION OF LIFE

UNDERSTANDINGS TO BE DEVELOPED

At the conclusion of this unit the students should have the following understandings:

1. How life may have arisen on the Earth
2. The chemical composition of living things
3. The function of the DNA molecule
4. The possibilities for life elsewhere in the universe
5. The mechanism of evolution
6. The possibilities for intelligent life elsewhere in the universe

A. A CASE FOR THE INORGANIC ORIGIN OF LIFE

The Earth probably began as a lifeless body of iron and rock 4.5 billion years ago. It is not known whether the Earth was a molten mass or a relatively cool planet at the time of its formation. Regardless of the temperature, the Earth was devoid of life when it formed. There are three possible explanations for the origin of life on the Earth.

SUPERNATURAL ORIGIN

This theory does not yield to a scientific explanation.

LIFE BROUGHT BY METEORITES

No meteorite to date has positively yielded living material.

LIFE STARTING FROM NONLIVING MATERIAL

Recent advances in scientific knowledge have shown that there is a strong possibility that life started from nonliving material in a manner consistent with our knowledge of science.

Activity V–1

DEFINING THE PROBLEM OF THE ORIGIN OF LIFE

The students are directed to construct a model of the newly formed Earth and of the Earth today. This may be done physically, or verbally as the report of a research paper. The students are then asked to list the major differences between the two models. The presence of life in the second model brings home the point that somehow life must have originated on Earth during the time period between the two models. (If this activity is used as a lead into Unit V, it will provide a smooth transition from Unit IV.)

Activity V–2

CONFIRMING THE POSSIBILITY THAT LIFE ARRIVED ON EARTH FROM OUTER SPACE

If life on Earth started with the arrival of organisms from outer space, then, according to the fossil record, the first organisms must have been bacterialike and must have made the trip to Earth under extremely hostile conditions. The following activity is designed to test the survival capability of micro-organisms under these conditions.

A bacteria colony is developed and a series of culture tubes are inoculated. One-quarter of the tubes are placed in liquid nitrogen for 30 minutes, one-quarter are placed in a vacuum for an equal length of time, and the third quarter are placed in both. The remaining tubes are used as a control. Although growth may be somewhat inhibited by the cold, all the cultures should survive the experiment. The variable not taken into account is time. In order for micro-organisms to complete a trip from one planet to another, vast amounts of time would be required.

B. THE COMPOSITION OF LIVING THINGS

THE FOUR BASIC ELEMENTS

The basic elements that make up living things are carbon, hydrogen, oxygen, and nitrogen. In the structures of living things, these elements are organized into amino acids that link together to form proteins. Proteins also serve as enzymes which catalyze all chemical reactions that take place in the organism. Since the amino acids are not only responsible for the structure but also for the chemical reactions of an organism, they are considered the basic building blocks of living things. There are approximately 20 different kinds of amino acids used by all living things. There may appear in a protein in any number or sequence. The sequence determines the type of protein.

Demonstration V–1

THE PRESENCE OF CARBON IN ALL LIVING THINGS

Various food items are selected by the teacher or students and heated in a frying pan until they are "burned to a crisp." In all cases the objects will turn black, indicating the presence of carbon. A magnesium ribbon may be burned as a control. This will produce a white oxide. It may then be pointed out that living things contain hydrogen, oxygen, and nitrogen as well as carbon.

Activity V–3

STRUCTURAL PROTEIN

Select several food materials and have the students guess or determine with a microscope which ones are cellular. Then have them look up whether or not the cellular foods provide protein.

Activity V–4

ACTION OF AN ENZYME

The enzyme in saliva breaks down starch into sugar. Have the students chew crackers until the taste changes. They will find that eventually the cracker begins to taste sweet. If a cracker is tested for sugar with Benedict's solution, the result will be negative. However, if another cracker is thoroughly mixed with saliva and then tested, the result will be positive. The starch has been broken down by the enzyme in the saliva.

Activity V–5

PROVING THE EXISTENCE OF PROTEIN IN LIVING THINGS

The students are instructed to bring in pieces of cellular food, either meat or vegetable. A small piece of the food is placed in a test tube and a few drops of nitric acid are added. The tube is heated over a small flame and then the acid is poured off. A few drops of ammonium hydroxide are added to the remaining piece of food, and a color change to green indicates the presence of protein. Other suitable controls should undergo the same procedure.

C. THE DNA MOLECULE

THE DNA CODE

Proteins are assembled in the cells according to a code which is "written" into a nucleic acid in the nucleus of each cell. Nucleic acids are made up of a sequence of nucleotides. There are only five nucleotides, but they can be arranged and may appear any number of times in one sequence. The most important nucleic acid is deoxyribonucleic acid (DNA).

The DNA controls the manufacture of protein. Free nucleotides line up along a segment of the DNA molecule to form a replica of the segment. This replica then detaches from the DNA. It contains the code for the assembly of the protein, which is accomplished when a specific intermediate molecule carrying an amino acid links up with the replica along the chain. The lineup of amino acids then links to form the protein. The assembled protein detaches itself and moves off into the cell.

The DNA has the ability to replicate itself, and since it provides the code for the structure and function of the cell, this code is transmitted to the daughter cells during mitosis.

Each living organism has is own set of DNA molecules and so each organism produces its own protein structures and enzymes. The structures and enzymes give the organism its characteristics; therefore the DNA determines the characteristics of the organism and its offspring.

Activity V–6

THE DNA MOLECULE

Obtain a picture or drawing of the DNA molecule. Using Styrofoam or clay balls and wire, have the students construct a segment of the DNA molecule. For a variation you can clip the molecule in half, with pliers, at the center bands and have two teams of students reassemble each side of the molecule to show how it replicates. The two new molecules should be identical, but if a mistake has been made it may be pointed out as a possible mutation.

D. THE PRIMORDIAL ORIGIN OF LIFE

AMINO ACIDS AND NUCLEOTIDES

Amino acids and nucleotides have been produced in the laboratory from constituents of a primitive atmosphere. Stanley Miller in 1952 produced amino acids from ammonia (NH_3), methane (CH_4), water vapor (H_2O), and hydrogen (H_2) by circulating the gases through an electrical discharge. Nucleotides have been produced in the laboratory in a similar manner. Both have been produced using ultraviolet light, heat, and bombardment by alpha particles. Cyril Ponnamperuma of the NASA Ames Research Center reported in 1964 of investigations undertaken to synthesize the constituents of the nucleic acid and protein molecules. The results showed that under primitive Earth conditions, molecules of biological significance can be synthesized. Amino acids and nucleotides produced by natural phenomena over a period of millions of years may have accumulated in the ocean until a chance combination formed a replicating molecule that may be called living.

Activity V–7

THE ORIGIN OF LIFE

Have the students construct an imaginary model of the primitive Earth just after formation. Be sure that the model shows the gases present, the temperature, and the fact that the lack of ozone meant that ultraviolet light was reaching the surface of the Earth. When the students have completed the model, read to them an account of Miller's experiment.

E. LIFE ON OTHER PLANETS

The following is a list of possible life-bearing objects within our solar system. After the name of each, the major arguments for or against the existence of life are given.

MOON

The surface of the Moon has a great temperature fluctuation from night to day. Also there is no water on the surface. Below the lunar surface the temperature may be warm enough, but there is no water in which the molecules can come together.

MARS

Parts of Mars change color with the seasons. This phenomenon may be caused by vegetation or by an inorganic mineral. There is little water and very little atmosphere. The temperature appears to be suitable for life.

VENUS

Evidence indicates that water vapor is not present. Because of the greenhouse effect the temperature may be as high as 400° C (Unit IV). The pressure may be extremely high, up to 8 Earth atmospheres.

JUPITER

Jupiter has the same gases as those used in Miller's experiment. Radio information indicates that electrical discharges are taking place. There is a region which has the proper temperature for life about 20 kilometers below the top of the clouds. If life exists on Jupiter, the organisms are probably very small, since organism size is probably inversely proportional to the strength of gravity.

ALL OTHER PLANETS

The other planets in the solar system may reasonably be eliminated on the basis of temperature alone.

The best way to look at this problem is to consider our galaxy as representative of all galaxies. According to the above theory of the origin of life on Earth, life will occur given favorable planetary conditions and a very long period of time. The first billion years of the Earth's history were probably required for life to form. This eliminates all planets around stars larger than the Sun, since the star would not have lived long enough to produce life (Unit III). Stars which are smaller than the Sun can support life on planets that are at about the same distance as the Earth. Recent astronomical data have indicated that many stars have planets around them. If one Sun-like star in 1 million has a planet that is at the same distance from the star as the Earth is from the Sun, then in our galaxy alone there would be 100,000 planets with conditions similar to those on Earth. There are billions of galaxies. The chances of life occurring elsewhere appear very great.

F. THE EVOLUTION OF HIGHER FORMS OF LIFE

THE EARLIEST KNOWN FORMS

The earliest known forms of life are fossilized bacteria found in rocks about 2 billion years old, and remains of simple plants, also 1 or 2 billion years old. The first 3 billion years of the Earth's history are a blank chapter in the book of life. Six hundred million years ago, at the start of the Cambrian era, the fossil record explodes into a profusion of living forms. Somewhat later, about 400 million years ago, nearly all the major divisions of animal life which exist on Earth today made their appearance in the fossil record. A line of ascent can be traced in the rocks from the earliest forms through the jawless fish to true fish, amphibians, and reptiles. About 60 million years ago, a type of small tree-dwelling mammal, resembling the modern tree shrew, tarsier, and lemur started a line of evolutionary development which led to the monkey, the ape, and the ancestor of modern man.

Each organism reproduces its own kind. The characteristics of the parents, that is, the genetic information, are carried to the offspring by exact replicas of the parent's DNA. According to this picture, living things should never change. But occasionally there is a mistake and the offspring is slightly different. The mistakes are called mutations. Mutations may also be produced by exposure to radiation. If the mutation is unfavorable, the offspring may never reproduce. If, however, the mutation is favorable, the offspring may succeed and reproduce, transmitting the favorable characteristic to its offspring and so on until the characteristic becomes established in the species after many generations.

A process exists in nature that has molded the forms of living organisms and guided the path of evolutionary development as surely as gravity molds the shapes and orbits of stars and planets. This is the process of natural selection, proposed by Darwin in 1859 with the publication of the Origin of Species. According to his theory, a single form of life evolves and possibly divides into several forms. Those forms which are poorly adapted for survival die out in subsequent generations. Those which are well adapted for survival continue for many generations to fill particular niches in the physical environment. Most of the forms of life can be understood with the help of the Darwinian theory. The story revealed by the fossil record is one of continual change and improvement, for only the improved forms of life survive sufficiently to leave a fossil record.

Activity V-8

EVOLUTION

Take a field trip to a museum of natural history. Require a report from each student on the development of a species of organism through the evolutionary process. Have the class make a geological calendar showing the development of each organism selected through the history of the Earth. Many students may find that organisms that are vastly different today have come from common ancestors.

G. THE POSSIBILITY OF INTELLIGENT LIFE ELSEWHERE IN THE UNIVERSE

The physical laws observed on the Earth are probably the same throughout the universe. If life originated on other planets, natural selection has taken place. Given enough time, intelligent life is a natural consequence. It is hard to conceive of life occurring on all favorable planets at the same time, or of evolution taking place at the same rate. Therefore, there may be many planets behind us in evolution. Conversely, many societies may be far ahead of us.

SAMPLE QUESTIONS

1. What are the primary elements of life?
2. What is the abundance of these elements compared to others in the universe?
3. What sources of energy may have helped these chemicals get organized into organic molecules?
4. What organic molecules are the fundamental building blocks of life?
5. What is the role of DNA in reproduction?
6. What is the role of DNA in evolution?
7. Defend or attack with evidence that life may exist elsewhere in the universe.
8. How does ecology contribute to evolution?
9. Give a case for the ability of life to spread throughout the universe.
10. If life occurs elsewhere, will higher forms evolve?
11. How would you attempt to communicate with intelligent beings from another planet?
12. Describe Miller's experiment which indicated possible pathways for the origin of life.
13. How does DNA replicate?
14. What functions do proteins perform in living things?
15. What is the difference between one protein and another?

PROBLEMS AND PROJECTS FOR FURTHER EXPLORATION

1. Start an aquarium in your classroom to observe the interrelationships of life forms.
2. Build a DNA molecule to show how it reproduces.
3. Select two different animals and trace them back to a common ancestor.
4. Collect materials on current research on the origin of life and write a report.
5. Develop with other members of the class a system of communication that might be used to communicate with intelligent beings from another planet.

AUDIOVISUAL AIDS

STORY IN THE ROCKS (19 min.) color Shell Oil Co. An elementary introduction to paleontology that shows how scientists are able to reconstruct the nature of life on Earth millions of years ago from fossils that have been preserved in rocks. This is a good film for average high school students.

THREAD OF LIFE (60 min.) color Bell Telephone Co. Film relates the history and progress of genetics and discusses recent findings on genes, chromosomes, and DNA. Excellent film for the average high school student.

GENE ACTION (16 min.) color Encyclopaedia Britannica Films. Laboratory demonstrations and effective animated diagrams are combined to illustrate the structure of DNA, to show how DNA replicates itself, and to explain how the DNA code determines the structure of a cell's proteins.

NATURAL SELECTION (16 min.) color Encyclopaedia Britannica Films. This film reports on three important experiments concerning the role of natural selection in evolution.

(1) A study of bird predation as a factor in the survival of variant species of moths.
(2) A study of natural selection among plant populations.
(3) A program to investigate the development or resistance among mosquitoes to modern insecticides.

Excellent film for all high school students.

Addresses are listed in the Appendix.

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Glasstone, Samuel: SOURCEBOOK ON THE SPACE SCIENCES. D. Van Nostrand Co., Inc., 1965. Intended for the reader with an elementary knowledge of the conventional sciences, particularly physics and chemistry. Use of mathematics minimal.

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Jastrow, Robert: RED GIANTS AND WHITE DWARFS. Harper & Row, Publishers, 1967. An interesting, thought-provoking book. Scholarly, yet easy to read. Presents a broad view of the universe. Of interest to both students and teachers.

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Addresses are listed in the Appendix.

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Rublowsky, John: IS ANYBODY OUT THERE? LIFE ON OTHER WORLDS. Walker & Co., 1962. A delightful little book for the student interested in astronomy. Deals with the intriguing subject of life on other worlds. All of the theories are based on current scientific opinion. Although it contains many scientific facts about the universe, its lively style can fire the child's imagination about an exciting topic.

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Addresses are listed in the Appendix.

Unit VI

Unit VI

MOTION, ROCKETS, AND GRAVITY

UNDERSTANDINGS TO BE DEVELOPED

At the conclusion of this unit the student should have the following understandings:

1. **Kepler's laws of planetary motion**
2. **Newton's three laws of motion**
3. **The physics of artificial Earth satellites**
4. **The characteristics of rockets**
5. **The fundamental properties of gravity**

A. THE WORK OF GALILEO, 16TH CENTURY

In the 16th and 17th centuries, Galileo experimentally investigated uniformly accelerated motion, particularly the motions of falling bodies. He made a vital contribution to the laws of motion by shifting emphasis from speed to acceleration and by establishing the quantitative law of motion for acceleration under a constant force.

The rate of change of speed of a moving object is called its acceleration.

$$a=\frac{v}{t}$$

For a falling body, the acceleration is constant if air resistance is neglected. The velocity attained depends upon the time elapsed.

$$v=at$$

When acceleration is uniform, the distance an object falls increases as the square of the time.

$$d=\frac{1}{2}v\times t=\frac{1}{2}(at)\times t=\frac{1}{2}at^2$$

Activity VI–1

BEHAVIOR OF FALLING BODIES

The students drop balls from the classroom window and time the descent. The ball should fall at least two stories to accurately determine the time. Using their data, they calculate the height of the window and then check it by lowering a weighted string and measuring it.

B. THE WORK OF NEWTON, 17TH CENTURY

LAWS OF MOTION

1. Every body continues in its state of rest or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed.

2. An object is accelerated in proportion to the forces applied. The force required depends upon the quantity of matter which the object contains.

   $$F\propto ma$$

   Newton introduced the term "mass" as a measure of the quantity of matter. Note that Newton's second law of motion sets acceleration proportional to applied force, whereas Aristotle's law had set speed proportional to force.

3. To every action there is opposed an equal reaction.

   $$m_1v_1=m_2v_2$$

Demonstration VI–1

NEWTON'S FIRST LAW OF MOTION

Newton's first law may be demonstrated by giving an object on a desk a push so that it will slide along and beyond the desk top. If it did not have a tendency to continue in a straight line, it would fall straight downward. The fact that an object has a tendency to remain at rest may be demonstrated by the old parlor trick of pulling a piece of cloth or paper out from under a glass of water.

Demonstration VI–2

NEWTON'S SECOND LAW OF MOTION

Newton's second law may be demonstrated by placing students of obviously different mass in chairs and having students of about the same strength push them. The lighter ones will be accelerated faster.

Demonstration VI–3

NEWTON'S THIRD LAW OF MOTION

Remove the horn from a 5-, 10-, or even 15-pound CO_2 fire extinguisher, leaving the brass nozzle or coupling. The participant stands on roller skates or on a small stout board, 10 inches wide and 1.5 to 2 feet long, on which are four ball-bearing wheels. The rider holds the extinguisher so that the nozzle is horizontal and aimed opposite to the desired direction of motion. On a smooth floor, even a few blasts will readily demonstrate Newton's third law. BE CERTAIN THAT NO ONE IS STANDING IN THE PATH OF THE ESCAPING GAS. THE VELOCITY AND PRESSURE ARE TREMENDOUS, AND AN EYE INJURY COULD RESULT.

C. THE PHYSICS OF ARTIFICIAL EARTH SATELLITES

ORBITAL VELOCITY

It is in theory possible that a cannon could be made with such power that if it were placed on the top of a mountain with its barrel directed horizontally, the ball fired from it would travel around the Earth without striking the ground. The combination of forward motion and downward deflection produced by gravity would curve the path of the projectile into a circular orbit around the Earth. From the relationship

$$F=ma=m\frac{v^2}{R}=G\frac{mM}{R^2}$$

comes the expression

$$v=\sqrt{\frac{MG}{R}}$$

(See Sec. VI–G.) The expression can be used to calculate the speed of a satellite moving in a circular orbit around the Earth at a certain distance R from the Earth's center.

If a satellite is launched with a speed that is insufficient to keep it in circular orbit, it will fall back and either strike the ground or be burned by friction in the dense air of the lower atmosphere. If a satellite is launched with a speed greatly in excess of the proper one, it will leave the Earth altogether.

The Moon is circling the Earth at a speed of 2280 mph, while a satellite orbiting 100 miles above the surface of the Earth requires a speed of 17,500 mph. Although the speed required to place a satellite in orbit diminishes as the altitude of the orbit increases, it should not be concluded that the task of orbiting a satellite is simplified by going to greater heights. More energy is lost in raising the satellite higher against the pull of gravity than is gained in the reduction of the forward speed required.

Activity VI–2

CALCULATION OF ORBITAL VELOCITY

Calculate the speed required to place a satellite in a low orbit 100 miles above the Earth's surface.

$$v=\sqrt{\frac{MG}{R}}$$

$$M_E=5.97\times10^{27}\text{ grams}$$
$$R_E=6.53\times10^{8}\text{ cm}$$
$$G=\frac{6.67\times10^{-8}\text{ cm}^3}{\text{gram sec}^2}$$

Substituting these values in the above formula, we obtain:

$$v=\sqrt{\frac{5.97\times10^{27}\times6.67\times10^{-8}}{6.53\times10^{8}}}\text{ cm/sec}$$
$$=\sqrt{\frac{39.8}{6.53}\times10^{11}}\text{ cm/sec}$$
$$=7.81\times10^{5}\text{ cm/sec}$$
$$=4.85\text{ mps}=17{,}500\text{ mph}$$

Similar calculations should be made by the students for different altitudes in order to determine the relationship between altitude and orbital velocity.

D. PERIODS OF SATELLITES

THE SIDEREAL PERIOD

We find a satellite's sidereal period by dividing the distance traversed in one transit of the orbital path by the orbital speed. The sidereal period ignores the rotation of the Earth and is the orbital period as it would be observed from a point far out in space.

$$T=\frac{2\pi R}{V},\qquad \text{Since } V=\sqrt{\frac{MG}{R}}$$

$$T=\frac{2\pi R}{\sqrt{\frac{MG}{R}}}=\frac{2\pi R^{3/2}}{\sqrt{MG}}$$

If both sides of this equation are squared, it can be recognized as Kepler's third law: $T^2 \propto R^3$

Inserting the mass of the Earth for M and changing the units to express T in minutes and R in miles, the formula becomes

$$T\ (\text{min}) = \frac{2\pi}{60}\sqrt{\frac{R^3}{MG}}$$

If the orbital radius is 4060 miles, T is 87 minutes, or approximately 1½ hours. At the distance of the Moon, $R=239{,}000$ miles, and T is about 39,600 minutes or 27½ days. For a 24-hour period the orbital radius is 22,300 miles. A satellite in such an orbit is called synchronous because it has the same period as the Earth's rotation.

Activity VI–3

CALCULATION OF ORBITAL PERIOD

Calculate the sidereal periods of the orbits of the satellites in *Activity VI–2*.

Activity VI–4

COMPUTATION OF ALTITUDE FOR SYNCHRONOUS SATELLITE

Satellites such as Syncom and Early Bird are in synchronous orbits. If such a satellite is moving east over the equator, it appears to stay over one position on the Earth, since its period is equal to the rotational period of the Earth. By solving for R the period equation given above, we obtain the following equation, in which $T=24$ hours.

$$R = \sqrt[3]{\frac{(60)^2\, T^2\, MG}{4\pi^2}}$$

(The correct answer is $R=26{,}260$ miles, which represents an altitude of 22,300 miles above the surface of the Earth.)

THE SYNODIC PERIOD

The time between successive passes over a given meridian of longitude is the synodic period. If the satellite is moving east, it must make more than one full circle of the Earth to catch the meridian, and the synodic period will be greater than the sidereal period. If the satellite is moving west, the synodic period is less than the sidereal period. The computation of the synodic period is beyond the scope of this discussion.

E. SHAPES OF ORBITS, ESCAPE VELOCITY

When a satellite travels in an elliptical orbit, the point closest to the center of the Earth is called the perigee, while the point farthest from the center is called the apogee.

If a satellite is to overcome the gravitational force of the Earth and become a space probe, it must achieve or surpass a certain minimum velocity.

$$V=\sqrt{\frac{2MG}{R}}=\sqrt{2}\sqrt{\frac{MG}{R}}$$

Minimum escape velocity is approximately 1.41 times circular orbital velocity at the altitude involved.

In the case of the Earth, escape velocity is 24,800 mph at the Earth's surface.

Activity VI-5

ESCAPE VELOCITY

Have the students calculate the escape velocities from the different planets. When the velocities have been tabulated, compare them with the atmospheric data in Unit IV. (Planets with low escape velocities cannot hold dense atmospheres.)

F. LAUNCH VEHICLES

PROPULSION

No demonstrations or activities have been suggested for the following section on rockets. However, an overall activity of building and launching model rockets is recommended as a program during any instruction on rockets. Nothing can take the place of a program of this nature for developing enthusiasm and interest. For a modest investment the materials may be obtained, including instructions and safety procedures for launch sites. Persons interested in model rocketry can obtain information and names of distributors of supplies from the National Association of Rocketry, 1239 Vermont Avenue, N.W., Washington, D.C. 20005.

Caution: A great number of accidents resulting in the permanent maiming of children have occurred from attempts to mix rocket fuel. Students should not be permitted to mix fuels. Solid propellant prepacked engines are available commercially. These engines are completely safe if handled according to instructions packed with each engine.

Liquid or solid fuel is burned in the interior of the rocket and converted into a hot gas, which escapes through the nozzle and supplies the motive force of the rocket. Since rockets operate outside of the atmosphere, they carry their oxidizer with them, usually in the form of liquid oxygen (lox) at a very low temperature (below −120° C).

As hot gases stream out of the nozzle of a rocket, they push back on the rocket casing and propel it forward. If air is present, the flow of gases out of the nozzle is impeded and becomes less effective in propelling the rocket forward.

The rocket is propelled away from the site of the launch at a speed that is dependent on the ratio of the mass of the exhaust gases to the total mass of the rocket and unburned fuel and on the velocity of the exhaust gases.

$$m_{\text{rocket}} v_{\text{rocket}} = m_{\text{fuel}} v_{\text{fuel}}$$

$$v_{\text{rocket}} = v_{\text{exhaust}} \frac{m_{\text{fuel}}}{m_{\text{rocket}}}$$

PROPULSION EQUATION

The actual speed attained is not as great as the momentum formula indicates. This is because the push of the burning gases accelerates the rocket casing and, in addition, the remaining unburned fuel and oxygen. The actual speed may be calculated by using the following expression developed with the aid of the calculus:

$$v_{\text{rocket}} = v_{\text{fuel}} \log_e \frac{m_{\text{rocket}} + m_{\text{fuel}}}{m_{\text{rocket}}}$$

For a rocket which is 90 percent fuel, the velocity works out to 2.3 times the velocity of the exhaust. If the propellant is kerosene and liquid oxygen, the gases exhaust at a speed of about 6300 mph yielding a rocket speed of $2.3 \times 6300 = 14{,}500$ mph. This is an insufficient speed for orbiting or escaping the Earth.

One way of increasing the rocket speed is by improving the mass ratio, that is, the ratio of the rocket plus fuel to the weight of the empty rocket. A large improvement in mass ratio is gained by dividing the rocket into two, three, or four stages that can be dropped off successively as their fuel is exhausted. The burn-out velocities of the separate stages are added to get the final velocity. Since the velocity depends on the natural logarithm of the mass ratio, one can show from the properties of logarithms that the sum of the logarithms of the ratios is equal to the logarithm of the product of the ratios. The Saturn V, for example, when loaded with a payload of 45 tons, has mass ratios for stages 1, 2, and 3 of 3.68, 3.13, and 3.09, respectively. The product gives a total mass ratio of 35.6. This mass ratio makes possible a rocket speed, neglecting gravity and air drag, of 32,000 mph.

HIGH-ENERGY PROPELLANTS

NASA is now using liquid oxygen and liquid hydrogen in the upper stages of such vehicles as the Saturn IB, Saturn V, and the Centaur. This combination increases exhaust velocity by one-third or more. The nuclear engine under development will exhaust heated hydrogen at twice the velocity of the oxygen-hydrogen combination. For future missions into deep space, arc jet and ion engines will provide very high exhaust velocities. Since the number of particles emitted will be relatively small, the thrust will be small. But these engines can operate for long periods of time. A spacecraft far from the Earth's gravitational field when pushed by these engines will accelerate slowly, but will eventually reach a tremendous velocity.

G. GRAVITY AND PLANETARY MOTION

The following is presented in outline form for supplementary use by advanced students. No attempt has been made to outline demonstrations or activities. The material is first treated historically, and then exercises in gravity are provided.

PLANETARY PHYSICS—HISTORY

1. Alphonse Borelli, 17th century
   The attractive force of gravity is exerted by the Sun on the planets, and bends their paths into ellipses.
2. Robert Hooke, 17th century
   Gravity acts on the Moon, the planets, and all celestial bodies.
3. Tycho Brahe, 16th century
   Provided very accurate observational data for the positions of the planets and other celestial bodies.
4. Johannes Kepler, 17th century
   Analyzed Brahe's data on the positions of the planets and derived three general laws of planetary motion.
   a. The orbit of each planet is an ellipse with the Sun at one focus. Kepler was the first astronomer to overthrow the circle and the epicycle, and establish the ellipse as the correct description of the motion of the planets.
   b. The radius vector sweeps over equal areas in equal intervals of time. A planet moves fastest when it is closest to the Sun and slowest when it is at its greatest distance in its elliptical orbit.
   c. The ratio of the cubes of the semimajor axes of the orbits of any two planets is equal to the ratio of the squares of their periods.

$$T^2 \propto R^3$$

d. The Earth is 93 million miles from the Sun, and revolves about the the Sun in 365.25 days or approximately 32 million seconds. Mars is 142 million miles from the Sun, or roughly 1.53 times farther than the Earth. Since $T^2 \propto R^3$, we have

$$\frac{T^2\text{ (Mars)}}{T^2\text{ (Earth)}}=\frac{R^3\text{ (Mars)}}{R^3\text{ (Earth)}}=(1.5)^3=3.55$$

and

$$\frac{T\text{ (Mars)}}{T\text{ (Earth)}}=\sqrt{3.55}=1.88$$

Hence, the Martian year is 1.88 times the length of a year on the Earth, or approximately 687 days.

5. Isaac Newton, 17th century

   a. A planet or any object moves in a straight line unless a force deflects it; therefore, a force must act on the planets to keep them circling around the Sun and a force must act on the Moon to keep it circling around the Earth.

   b. The force of gravity that the Earth exerts on objects at its surface is identical with the force attracting the Moon to the Earth and the planets to the Sun.

   c. The gravitational force of attraction between any two objects of masses m and M, separated by a distance R, is:

$$F=\frac{GmM}{R^2}$$

6. Combine the law of universal gravitation with the second law of motion and derive the value of the orbital velocity of a planet at a distance R from the Sun:

$$\frac{GmM}{R^2}=ma=\frac{mv^2}{R}$$

$$v=\sqrt{\frac{MG}{R}}\text{ (as before)}$$

EXERCISES IN GRAVITY

1. The derivation of the inverse-square law of gravity from Kepler's third law is among the most important calculations ever performed in the history of science.

   a. The second law of motion is $F=ma$, with F being the force acting on a planet, m its mass, and a its acceleration in motion around the Sun. Newton set for himself the task of determining the force by deducing the acceleration from observations on the motion of the planet.

b. For a body moving in a circular orbit, the centripetal acceleration is equal to the velocity squared divided by the radius of the circle.

$$a_c=\frac{v^2}{R}$$

c. $F=ma=\frac{mv^2}{R}$

d. For a body moving in a circular orbit

$$v=\frac{\text{Distance around the orbit}}{\text{Time of one circuit}}=\frac{2\pi R}{T}$$

e. Thus,

$$F=\frac{mv^2}{R}=\frac{m4\pi^2R^2}{RT^2}$$

f. Kepler's third law states that $T^2=C\cdot R^3$

g. Substituting T^2 in expression (e) above we find

$$F=\frac{m4\pi^2}{C}\cdot\frac{1}{R^2}$$

The force holding a planet in orbit falls off as the square of the distance R to the sum.

2. Calculate the acceleration of a falling object near the Earth's surface and the acceleration of the Moon toward the Earth.

a. As shown in Sec. VI–A, $d=\frac{1}{2}at^2$.

A measurement of d and t will yield a. If we let a body fall 16 feet, the time required is found to be 1 second. Then

$$16\text{ ft}=\tfrac{1}{2}a(1\text{ sec})^2$$
$$a=32\text{ ft/sec}^2$$

At the surface of the Earth gravitational acceleration is approximately equal to 32 ft/sec².

b. The acceleration of the Moon toward the Earth can be calculated by using the expression

$$a=\frac{v^2}{R}$$

$$v=\frac{2\pi\times 239{,}000\text{ miles}}{27.3\times 86{,}400\text{ sec}}=0.64\text{ miles/sec}=3380\text{ ft/sec}$$

$$a=\frac{(3380\text{ ft/sec})^2}{239{,}000\text{ miles}\times 5280\text{ ft/mile}}=0.0089\text{ ft/sec}^2$$

c. The ratio of the Moon's acceleration toward the Earth to the acceleration of gravity near the Earth's surface is

$$\frac{0.0089}{32}=\frac{1}{3596}$$

d. If the inverse-square law is applicable, the predicted ratio is 1/3600. This is true because

$$F=\frac{GMm}{R^2}=ma$$

$$a=\frac{GM}{R^2}$$

Thus, the acceleration of any body toward the Earth should vary inversely as the square of the distance between the body and the center of the Earth. The radius of the Earth is about 3960 miles. The center of the Moon is about 239,000 miles from the center of the Earth. If the inverse-square law is universally applicable, the force of the Earth's gravity on the Moon will be weaker than on objects at the Earth's surface in the ratio of $(3960/239{,}000)^2$, or one part in 3600.

With the fact that the value of g at the location of the Moon is 0.0089 ft/sec^2 (very small compared with 32 ft/sec^2 at the surface of the Earth), it can be verified that it would take the Moon a little more than 15 seconds to move 1 foot toward the Earth, if it were stopped in its orbit and allowed to fall.

SAMPLE QUESTIONS

1. An object accelerating at 16 m/sec^2 from rest will take how long to travel 200 meters?

2. A stone dropped into a well on the Earth requires 4.5 seconds to reach the bottom. How deep is the well?

3. How many newtons are required to accelerate a 100-kilogram mass at the rate of 20m/sec^2?

4. The Earth is 1.5×10^8 kilometers from the Sun. What is the mass of the Sun, if the period of the Earth is 1 year?

3

5. What is the mass ratio of a rocket which is 95 percent hardware?

6. What is the altitude of a satellite which has a period of 24 hours?

7. A 4000-newton force is exerted on a 120-kilogram object for 1 minute. What is the final velocity of the object?

8. What is the acceleration caused by gravity on the surface of the Moon?

9. What is the escape velocity from Jupiter? from Mars?

10. State Newton's three laws.

11. Describe how each of Newton's laws applies to a rocket launch.

12. Explain how an astronaut is weightless in orbit.

13. Explain why the Moon has no atmosphere and Jupiter has a very dense one.

14. What is the meaning of synchronous orbit?

15. What experimental advantages would a physicist have on the Moon?

PROBLEMS AND PROJECTS FOR FURTHER EXPLORATION

1. Conceive an orbital mission and design a rocket for the mission.

2. Research the history of the laws of motion from ancient times to the present. Present a report on your findings.

3. Write a story concerning the effects of a different gravity on future astronauts.

4. Build a model of a NASA spacecraft.

5. Research the effects of relativity on Newtonian physics and present a report to the class.

6. Investigate the effects of the Moon's reduced gravity, one-sixth of Earth gravity, on physical or athletic activity on the Moon.

m

7. Make a list of the various satellites that have been put into synchronous orbits, such as Syncom, Early Bird, and ATS. What practical benefits may result from the use of such satellites?

8. List and describe briefly the various major NASA launch vehicles.

9. Write a paper about propulsion systems based on nuclear or electric power.

10. Write a paper about the problems involved in making a space trip lasting months or years to another star system.

AUDIOVISUAL AIDS

SPACE ORBITS (18 min.) color U.S. Air Force. This film explains the basic facts of orbital patterns and forces which produce them. It explains those patterns in relation to space missions of missiles, satellites, lunar probes, and space travelers.

DOWN TO EARTH (13 min.) color U.S. Air Force. Deals with the reentry problem of space vehicles and the research that led to the development of a recoverable nosecone for the Titan ICBM. This is a good film for the average high school student.

UNIVERSAL GRAVITATION (31 min.) color Modern Learning Aids. The law of universal gravitation is derived by imagining a solar system of one star and one planet. The kinematics and dynamics of planetary motion are demonstrated using various models. This is an excellent film for the average and above-average high school student. Satellite orbits are displayed using a digital computer.

ISAAC NEWTON (14 min.) color Coronet Instructional Films. Biographical film.

GALILEO (14 min.) color Coronet Instructional Films. Biographical film.

SATELLITE ORBITS (20 min.) color Rensselaer Polytechnic Institute. Orbits are demonstrated with use of electronic planetarium.

CENTRIPETAL FORCE AND SATELLITE ORBITS (11 min.) color Coronet Instructional Films.

ELLIPTIC ORBITS (19 min.) b/w Modern Learning Aids. PSSC physics film.

FREE FALL AND PROJECTILE MOTION (27 min.) b/w Modern Learning Aids. PSSC physics film.

SATURN PROPULSION SYSTEMS HQa 77. 1962. (14 min.) color National Aeronautics and Space Administration. The theory of reaction engines and the application of the theory in the Saturn propulsion system.

ELECTRIC PROPULSION HQ 96. 1965. (24 min.) color National Aeronautics and Space Administration. Shows in nontechnical terms what electric propulsion is, how it works, why it is needed, its present status and program for development, and how it may be used for both manned and unmanned missions.

Addresses are listed in the Appendix.

TEACHER BIBLIOGRAPHY

Ahrendt, Myrl H.: THE MATHEMATICS OF SPACE EXPLORATION. Holt, Rinehart & Winston, Inc., 1965. Excellent teacher reference, covering motion, mass, weight, measurement in space, orbits, launch, and space flight. Problems included with answers in back. English system used.

Bennett, Clarance E.: PHYSICS WITHOUT MATHEMATICS. Barnes & Noble, Inc., 1959. A brief, simple review of basic laws of force and motion.

Branley, Franklyn M.: EXPERIMENTS ON THE PRINCIPLES OF SPACE TRAVEL. Thomas Y. Crowell, 1955. Helps the reader understand the difference between fact and fiction in the field of space exploration.

Branley, Franklyn M.: EXPERIMENTS IN SKY WATCHING. Thomas Y. Crowell, 1959. Contains a number of ideas for astronomy projects.

Cohen, I. Bernard: BIRTH OF A NEW PHYSICS. Anchor Books, 1960. Chapter 6, on Kepler's celestial music, discusses the eclipse and how it is related to bodies of the universe. A summary of Kepler's three laws with a mathematical interpretation and a final section on Kepler versus Copernicus is included.

Dull, Charles; Metcalfe, H. Clark; and Williams, John E.: MODERN PHYSICS. Holt, Rinehart & Winston, 1963. Excellent for review of development of laws of force and motion; problems worked out for each law and development thereof.

Gamow, George: GRAVITY. Anchor Books, 1962. The author presents an understandable yet complex view of gravity from Newton to Einstein.

Gamow, George: MATTER, EARTH AND SKY. Prentice-Hall, 1965. Deals with the motion of bodies and the action of forces in producing or changing their motion. Includes work, energy, and rockets. Uses graphs, illustrations and diagrams. Questions and problems at the end of each chapter with answers.

Gardner, Marjorie H.: CHEMISTRY IN THE SPACE AGE. Holt, Rinehart & Winston, 1965. A valuable addition to the scanty information now given in regular textbooks on the chemistry of space propulsion.

Glasstone, Samuel: SOURCEBOOK ON THE SPACE SCIENCES. D. Van Nostrand & Co., Inc., 1965. Intended for the reader with an elementary knowledge of the conventional sciences, particularly physics and chemistry. Mathematics is at a minimum.

Krauskopf, Konrad; and Beiser, Arthur: FUNDAMENTALS OF PHYSICAL SCIENCE. McGraw-Hill Book Co., Inc., 1966. Vivid, up-to-date photographs enhance the effectiveness of the text. The laws of motion are developed in chapter 3 in a lucid manner with the help of appropriate diagrams. There is an instructor's manual available which includes experiments and exercises.

Massey, Harrie: SPACE PHYSICS. Cambridge Univ. Press, 1964. The text requires a knowledge of calculus. It discusses the methods and procedures involved in the study of space, such as radar and radio observations, infrared observations, and space vehicles for lunar studies and probes.

Ripley, Jr., Julien A.: THE ELEMENTS AND STRUCTURE OF THE PHYSICAL SCIENCES. John Wiley & Sons, Inc., 1964. Contains an intermediate level treatment of satellite mechanics, a discussion of Greek astronomy, and a rather thorough discussion of cosmology and cosmogony. See especially chapters 4, 5, 7, and 21.

Rogers, Eric M.: PHYSICS FOR THE INQUIRING MIND. Princeton Univ. Press, 1960. An excellent text covering all fields of physics. Although this book contains considerable historical astronomy beginning with the ancients, it may be consulted for discussions of all the physical phenomena encountered in the syllabus.

Rusk, Rogers: INTRODUCTION TO COLLEGE PHYSICS. Appleton-Century-Crofts, 1954. Covers speed and velocity, acceleration, falling bodies, projectiles, circular motion. Questions and problems included.

Semat, Henry: FUNDAMENTALS OF PHYSICS. Holt, Rinehart & Winston, 1966. A readable text in all phases of physics.

Sutton, Richard: THE PHYSICS OF SPACE. Holt, Rinehart & Winston, 1965. Principles in the field of physics are used to understand space science. The topics include measuring angles, laws of gravitation, satellites and energy, time, and Earth in space.

Trinklein, Frederick; and Huffer, Charles M.: MODERN SPACE SCIENCE. Holt, Rinehart & Winston, 1961. A basic textbook that reaches into a number of sciences. A very good text or reference book for students or teachers of astronomy.

Van Allen, James: SCIENTIFIC USES OF EARTH SATELLITES. Univ. of Michigan Press, 1958. A collection of papers by different authors on Earth satellites. All articles are expertly written.

Wyatt, Stanley: PRINCIPLES OF ASTRONOMY. Allyn & Bacon, 1964. Explains simple and technical aspects of apparent and absolute magnitude with calculations as well as principles of interplanetary flight.

Addresses are listed in the Appendix.

STUDENT BIBLIOGRAPHY

Barnett, Lincoln: THE UNIVERSE AND DR. EINSTEIN. W. Sloane Associates, 1961. A well-written account of relativity, recommended for brighter students.

Beauchamp, Wilbur; et al.: EVERYDAY PROBLEMS IN SCIENCE. Scott, Foresman & Co., 1963. An excellent text with good illustrations and student experiments included.

Bondi, Herman: THE UNIVERSE AT LARGE. Anchor Books, 1960. Chapter 9, "The Law of Gravitation," contains a readable account of Newton's law of gravitation followed by a short passage entitled "Einstein's Gravity."

Branley, Franklyn M.: EXPERIMENTS IN THE PRINCIPLES OF SPACE TRAVEL. Thomas Y. Crowell, 1955. Helps the reader to understand the difference between fact and fiction in the field of space exploration.

Branley, Franklyn M.: THE MOON, EARTH'S NATURAL SATELLITE. Thomas Y. Crowell, 1960. Chapters on such topics as moonlight, eclipses, tides, reaching the Moon, and why the Moon stays in orbit.

Elliott, L. Paul; and Wilcox, William F.: PHYSICS—A MODERN APPROACH. The Macmillan Co., 1960. Good illustrative material for development of laws of force and motion. Useful summary and conclusions at end of each chapter as well as suggested projects and additional reading list.

Fenton, C. L. and M. A.: WORLDS IN THE SKY. The John Day Co., Inc., 1963. An easy-to-read, elementary book on astronomy and rocket travel. The index gives a pronunciation guide.

Gamow, George: GRAVITY. Anchor Books, 1962. An excellent discussion of gravity that is simple enough for the student to understand.

Kondo, Herbert: ADVENTURE IN SPACE AND TIME—THE STORY OF RELATIVITY. Holiday House, 1966. A small, amply illustrated book describing Einstein and his theories. Ideal for the interested student with a limited reading ability.

National Aeronautics and Space Administration: ROCKET PROPULSION. S-1, Code FGC-1, NASA, 1967. A brief discussion of propulsion systems and fuels.

National Aeronautics and Space Administration: SPACE NAVIGATION. NF-37, Code FGC-1, NASA, 1967. A brief nontechnical report of how an orbited spacecraft is guided to its destination.

National Aeronautics and Space Administration: SPACE LAUNCH VEHICLES. NF-8, Code FGC-1, NASA, 1967. Facts and figures on the launch vehicles used by NASA to launch spacecraft.

National Aeronautics and Space Administration: U.S. LAUNCH VEHICLES FOR PEACEFUL EXPLORATION OF SPACE. NF-20, Code FGC-1, NASA, 1965. Color pictures of the principal NASA launch vehicles.

Stine, George Harry: HANDBOOK OF MODEL ROCKETRY. NAR Official Handbook. Follett Publishing Co., 1965. Basic information and mathematics on rocketry pertinent to space science, written and illustrated for use by junior and senior high school students.

Addresses are listed in the Appendix.

appendix

appendix

A. ADDRESSES OF FILM DISTRIBUTORS

Bell Telephone Co. (Call office of local telephone company.)

Coronet Instructional Films, Coronet Building, 65 E. South Water St.,
Chicago, Ill. 60601

Encyclopaedia Britannica Films, 425 N. Michigan Ave., Chicago, Ill.
60611

General Dynamics Corp., Public Relations, Film Library, 1 Rockefeller Plaza, New York, N.Y. 10020

McGraw-Hill Films, 330 W. 42d St., New York, N.Y. 10036

Modern Learning Aids, 1212 Avenue of the Americas, New York,
N.Y. 10036

National Aeronautics and Space Administration, Code FAD,
Washington, D.C. 20546

National Educational Television Film Service, Indiana University,
Bloomington, Ind. 47401

Rensselaer Polytechnic Institute, Troy, N.Y. 12181

Shell Oil Co., Shell Film Library, 450 N. Meridian St., Indianapolis,
Ind. 46204

Teaching Film Custodians, Inc., 25 West 43d St., New York, N.Y. 10036

U.S. Atomic Energy Commission, Division of Public Information, Audiovisual Branch, Washington, D.C. 20545

U.S. Air Force, Aerospace Audiovisual Film Service, Air Force Film Library Center, 8900 S. Broadway, St. Louis, Mo. 63125

B. ADDRESSES OF PUBLISHERS

Abelard-Schuman, Ltd., 6 W. 57th St., New York, N.Y. 10019

Addison-Wesley Publishing Co., Inc., Reading, Mass. 01867

Allyn & Bacon, Inc., 470 Atlantic Ave., Boston, Mass. 02110

American Elsevier Publishing Co., Inc., 52 Vanderbilt Ave., New York, N.Y. 10017

American Heritage Publishing Co., Inc., 551 Fifth Ave., New York, N.Y. 10017

Anchor Books, Doubleday & Co., Inc., 277 Park Ave., New York, N.Y. 10017

Appleton-Century-Crofts, 440 Park Ave. S., New York, N.Y. 10016

Bantam Books, Inc., 271 Madison Ave., New York, N.Y. 10016

Barnes & Noble, Inc., 105 Fifth Ave., New York, N.Y. 10003

Basic Books, Inc., Publishers, 404 Park Ave. S., New York, N.Y. 10016

W. A. Benjamin, Inc., 1 Park Ave., New York, N.Y. 10016

Cambridge University Press, 32 E. 57th St., New York, N.Y. 10022

P. F. Collier, Inc., 866 Third Ave., New York, N.Y. 10022

Columbia University Press, 440 W. 110th St., New York, N.Y. 10025

Thomas Y. Crowell Co., 201 Park Ave. S., New York, N.Y. 10003

Doubleday & Co., Inc., 277 Park Ave., New York, N.Y. 10017

Dover Publications, Inc., 180 Varick St., New York, N.Y. 10014

E. P. Dutton & Co., Inc., 201 Park Ave. S., New York, N.Y. 10003

Fawcett Publications, Inc., Fawcett Place, Greenwich, Conn. 06830

Follett Publishing Co., 1010 W. Washington Blvd., Chicago, Ill. 60607

W. H. Freeman & Co., Publishers, 660 Market St., San Francisco, Calif. 94104

Ginn & Co., Statler Bldg., Back Bay, P. O. Box 191, Boston, Mass. 02117

Golden Press, Inc., 850 Third Ave., New York, N.Y. 10022

Hafner Publishing Co., Inc., 31 E. 10th St., New York, N.Y. 10003

Harcourt, Brace & World, Inc., 757 Third Ave., New York, N.Y. 10017

Harper & Row, Publishers, 49 E. 33d St., New York, N.Y. 10016

Harvard University Press, 79 Garden St., Cambridge, Mass. 02138

Holden-Day, Inc., 500 Sansome St., San Francisco, Calif. 94111

Holiday House, Inc., 18 E. 56th St., New York, N.Y. 10022

Holt, Rinehart & Winston, Inc., 383 Madison Ave., New York, N.Y. 10017

Interscience Publishers, Inc., 605 Third Ave., New York, N.Y. 10016

The John Day Co., Inc., 62 W. 45th St., New York, N.Y. 10036

Alfred A. Knopf, Inc., 501 Madison Ave., New York, N.Y. 10022

J. B. Lippincott Co., E. Washington Sq., Philadelphia, Pa. 19105

Littlefield, Adams & Company, 81 Adams Dr., Totowa, N.J. 07512

Lyons & Carnahan, 407 E. 25th St., Chicago, Ill. 60616

McGraw-Hill Book Co., 330 W. 42d St., New York, N.Y. 10036

The Macmillan Co., 866 Third Ave., New York, N.Y. 10022

Charles E. Merrill Books, Inc., 1300 Alum Creek Dr., Columbus, Ohio 43216

National Aeronautics and Space Administration, Code FGC–1, Washington, D.C. 20546 (For current information, request a copy of "NASA Publications List.")

Natural History Press, Doubleday & Co., Inc., 277 Park Ave., New York, N.Y. 10017

The New American Library, Inc., 1301 Avenue of the Americas, New York, N.Y. 10019

W. W. Norton & Co., Inc., 55 Fifth Ave., New York, N.Y. 10003

Orion Press, Grossman Publishers, Inc., 125A E. 19th St., New York, N.Y. 10003

Oxford University Press, Inc., 200 Madison Ave., New York, N.Y. 10016

L. C. Page & Co., Inc., 19 Union Sq. W., New York, N.Y. 10013

Prentice-Hall, Inc., Englewood Cliffs, N.J. 07632

Princeton University Press, Princeton, N.J. 08540

G. P. Putnam's Sons, 200 Madison Ave., New York, N.Y. 10016

Random House, Inc., 457 Madison Ave., New York, N.Y. 10022

The Ronald Press Co., 79 Madison Ave., New York, N.Y. 10016

Roy Publishers, Inc., 30 E. 74th St., New York, N.Y. 10021

St. Martin's Press, Inc., 175 Fifth Ave., New York, N.Y. 10010

W. B. Saunders Co., W. Washington Sq., Philadelphia, Pa. 19105

Scholastic Book Services, 50 W. 44th St., New York, N.Y. 10036

Scott, Foresman & Co., 1900 E. Lake Ave., Glenview, Ill. 60025

Signet Science Library, The New American Library, Inc., 1301 Avenue of the Americas, New York, N.Y. 10019

The L. W. Singer Co., Inc., 501 Madison Ave., New York, N.Y. 10022

William Sloane Associates, William Morrow & Co., Inc., 425 Park Ave. S., New York, N.Y. 10016

Sterling Publishing Co., Inc., 419 Park Ave. S., New York, N.Y. 10016

Time-Life Books, a division of Time, Inc., Time & Life Bldg., Rockefeller Center, New York, N.Y. 10020

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